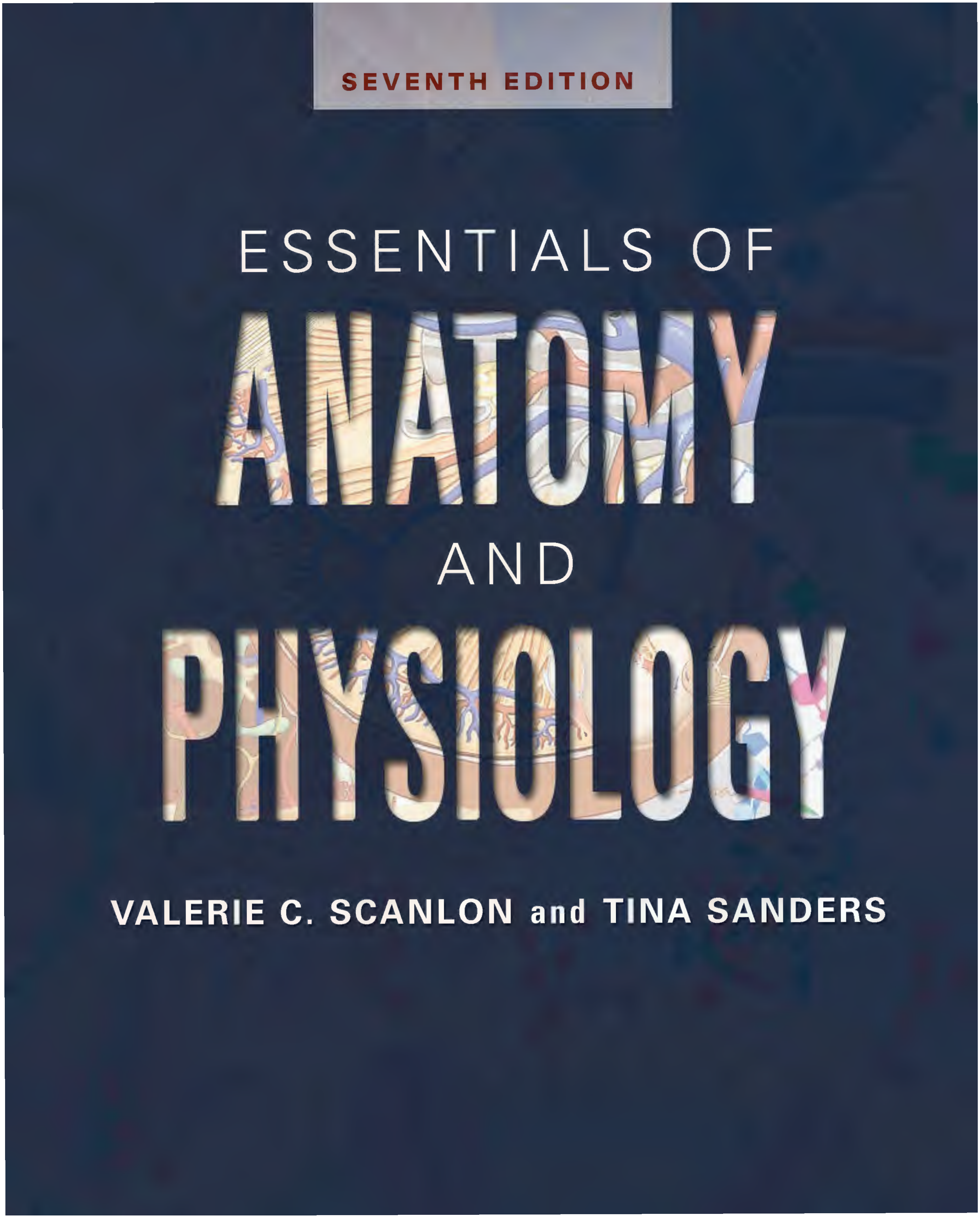


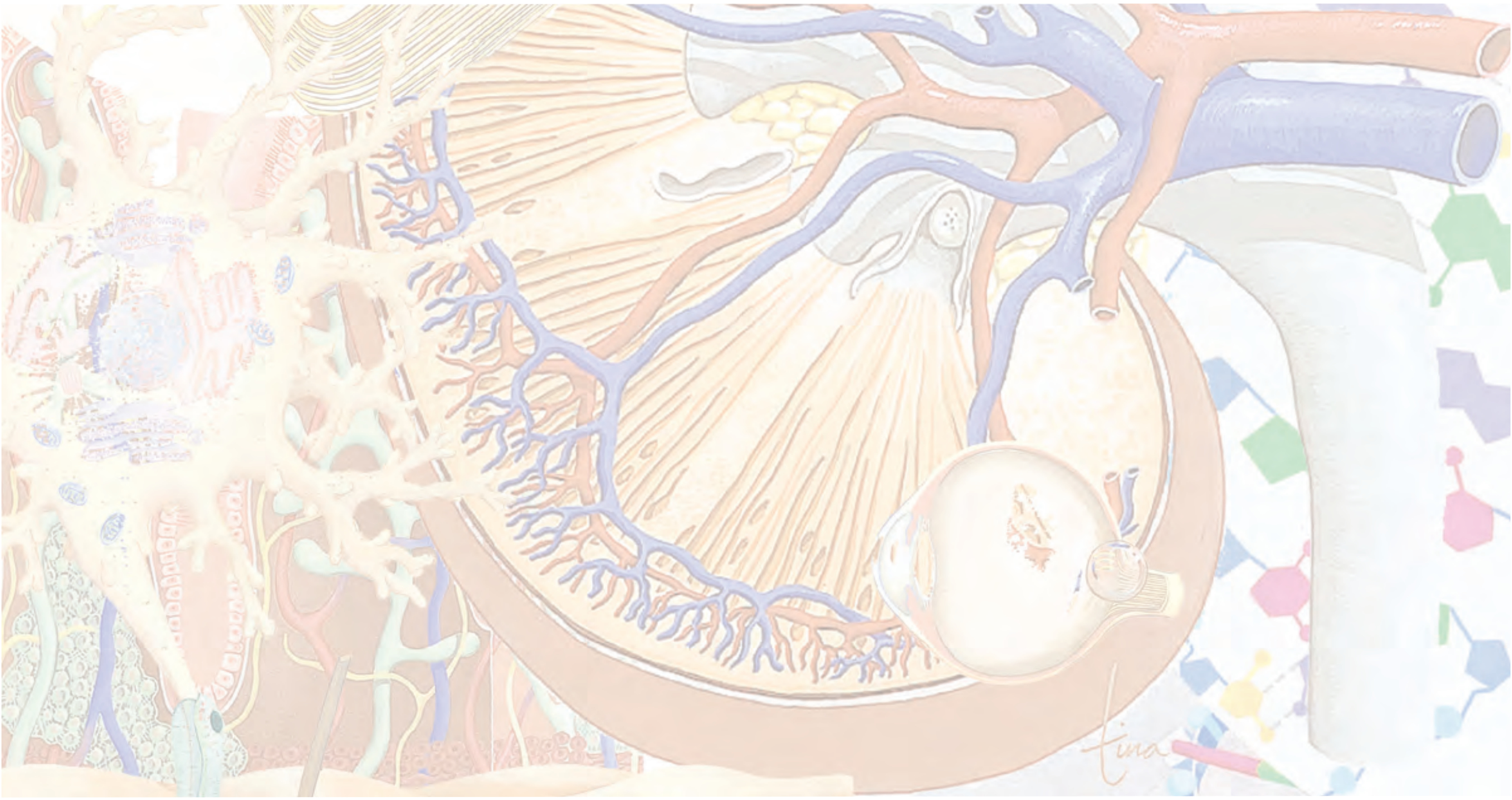
SEVENTH EDITION

ESSENTIALS OF ANATOMY AND PHYSIOLOGY

VALERIE C. SCANLON and TINA SANDERS

SEVENTH EDITION

ESSENTIALS OF
ANATOMY
AND
PHYSIOLOGY



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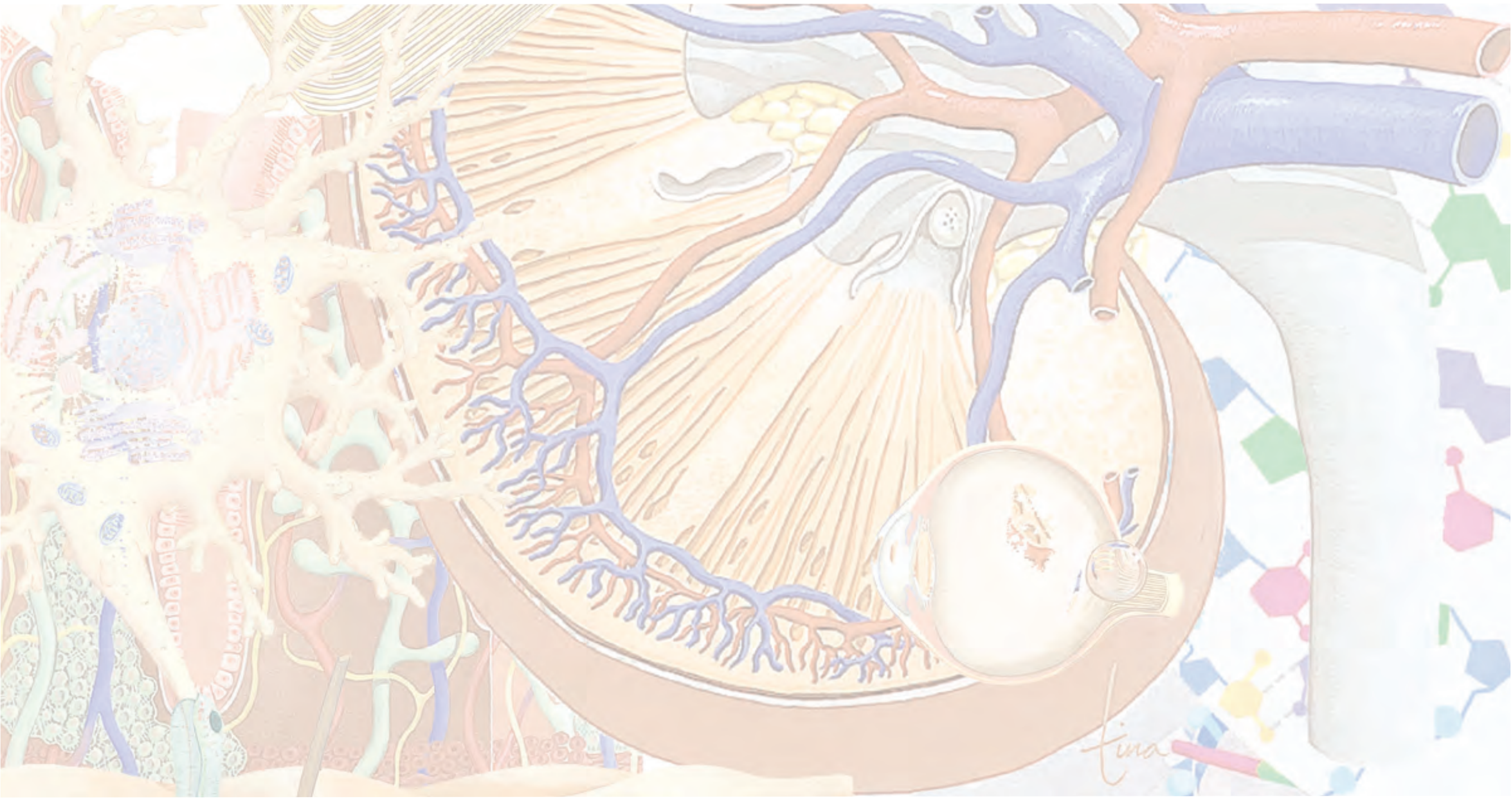

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To my students, past and present
VCS

To Brooks, for his encouragement
TS

PREFACE TO THE SEVENTH EDITION

Once again, we extend our gratitude to all of you who have used previous editions of *Essentials of Anatomy and Physiology* and are considering adopting our seventh edition. We are pleased to welcome new readers as well, and we thank you for choosing our book.

The seventh edition remains focused on presenting basic anatomy and physiology with the clarity of the text complemented and enhanced by superb illustrations. The text has been updated in many small ways to remain contemporary. These include brief discussions of our microbiota in Chapter 1 (and appropriate later chapters), the oligosaccharides in breast milk in Chapter 2, epigenetics and primary cilia in Chapter 3, connective tissue disorders in Chapter 4, motor units and the muscle hormone irisin in Chapter 7, celiac disease in Chapter 16, human papillomavirus in Chapter 20, and evaluation of fetal DNA in maternal blood for prenatal testing in Chapter 21. Chapter 12 has been revised and now begins with a description of cardiac muscle tissue, pulling together material from previous chapters.

All of the For Further Thought sections now end with at least one illustration question. New ones include the relationship of organ systems in Chapter 1, the hydrogen bonds formed by water molecules in Chapter 2, effects of sunlight on the skin in Chapter 5, a nerve pathway (to be named by the student) in Chapter 8, the hormones of stressful situations in Chapter 10, a time line of immune responses in Chapter 14, hormones of the duodenum in Chapter 16, regulation of body temperature in Chapter 17, and relationships of the reproductive organs to other organ systems in Chapter 20. When the students have labeled the picture and answered the questions, the whole then becomes an integral part of the chapter. We hope you will consider assigning these questions, and that students will find them enjoyable and helpful.

Colleagues, please keep in mind that the Instructor's Guide contains a full list of these additions in the "New to This Edition" section for each chapter of the textbook, as well as detailed answers to all of the For Further Thought questions.

As always, your comments and suggestions will be most welcome, and they may be sent to us in care of the publisher: F. A. Davis Company, 1915 Arch Street, Philadelphia, PA 19103.

Valerie C. Scanlon

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TO THE INSTRUCTOR

The start of the 21st century has already brought many advances in the science and art of medicine and health care; many of these were made possible by research and discoveries in the basic sciences. Teachers of introductory anatomy and physiology may wish to include some of these discoveries yet will want to maintain their emphasis on the normal structure and function of the human body. Those are the goals of this textbook: to add a little of the new to the foundation of long-standing knowledge and to make all of this material readily accessible to students with diverse backgrounds and varying levels of educational preparation.

No prior knowledge of biology or chemistry is assumed, and even fundamental terms are defined thoroughly. Essential aspects of anatomy are presented clearly and reinforced with excellent illustrations. Essential aspects of physiology are discussed simply yet with accuracy and precision. The illustrations complement the text material and foster comprehension on the part of the student. As you will see, these are images in which detail is readily apparent and all important parts have been labeled. Illustrations of physiology lead the student step-by-step. Wherever appropriate, the legends refer students to the text for further description or explanation. Each illustration also has a question for the student; the illustration questions in each chapter form an ongoing self-test. (The answers are given in Appendix G.)

The text has three unifying themes: the relationship between physiology and anatomy, the interrelations among the organ systems, and the relationship of each organ system to homeostasis. Although each type of cell, tissue, organ, or organ system is discussed simply and thoroughly in itself, applicable connections are made to other aspects of the body or to the functioning of the body as a whole. Our goal is to provide your students with the essentials of anatomy and physiology, and in doing so, to help give them a solid foundation for their future work and an appreciation for the incredible living organism that is the human body.

The sequence of chapters is a very traditional one. Cross-references are used to remind students of what they have learned from previous chapters. Nevertheless, the textbook is very flexible, and, following the introductory four chapters, the organ systems may be covered in almost any order, depending on the needs of your course.

Each chapter is organized from the simple to the more complex, with the anatomy followed by the physiology. The Instructor's Guide presents modifications of the topic sequences that may be used, again depending on the needs of your course. Certain more advanced topics may be omitted from each chapter without losing the meaning or flow of the rest of the material, and these are indicated, for each chapter, in the Instructor's Guide.

Clinical applications are set apart from the text in boxed inserts. These are often aspects of pathophysiology that are related to the normal anatomy or physiology in the text discussion. Each box presents one topic and is referenced at the appropriate point in the text. This material is intended to be an integral part of the chapter but is set apart for ease of reference and to enable you to include or omit as many of these topics as you wish. The use of these boxes also enables students to read the text material without interruption and then to focus on specific aspects of pathophysiology. A comprehensive list of the boxes appears inside the book's front and back covers, and another list at the beginning of each chapter cites the boxes within that chapter.

Tables are utilized as summaries of structure and function, to present a sequence of events, or additional material that you may choose to include. Each table is referenced in the text and is intended to facilitate your teaching and to help your students learn.

New terms appear in bold type within the text, and all such terms are fully defined in an extensive glossary, with phonetic pronunciations. Bold type may also be used for emphasis whenever one of these terms is used again in a later chapter.

Each chapter begins with a chapter outline and student objectives to prepare the student for the chapter itself. New terminology and related clinical terms are also listed, with phonetic pronunciations. Each of these terms is fully defined in the glossary, with cross-references back to the chapter in which the term is introduced.

At the end of each chapter are review questions and a study outline. The study outline includes all of the essentials of the chapter in a concise form. The review questions may be assigned as homework or used by the students as a review or self-test. Following each question is a page reference in parentheses. This reference cites the page(s) in the chapter on which the content needed to answer the question correctly can be found. The answers themselves are included in the Instructor's Guide. The questions in the sections titled For Further Thought may be used in a variety of ways, and the answers are in the Instructor's Guide.

An important supplementary learning tool for your students is available in the form of a *Student Workbook* that accompanies this text. For each chapter in the textbook, the workbook offers fill-in and matching-column questions, figure-labeling and figure-coloring exercises, and crossword puzzles based on the chapter's vocabulary list. Also included are three comprehensive, multiple-choice chapter tests to provide a thorough review. All answers are provided at the end of the workbook.

Ancillary materials for the teacher using this text are all available on the F.A. Davis website (please contact your F.A. Davis sales representative for access information): a complete Instructor's Guide, a test bank using three formats, an Interactive Teaching Tool presentation of the text illustrations, with related questions for students, podcasts of the chapter study outlines, and PowerPoint lecture outlines. The Instructor's Guide contains notes on each chapter's organization and content (useful for modifying the book to your specific teaching needs), topics for class discussion, answers to the chapter review questions from the textbook, and detailed answers to the For Further Thought questions.

Suggestions and comments from colleagues are always valuable, and yours would be greatly appreciated. When we took on the task of writing and illustrating this textbook, we wanted to make it the most useful book possible for you and your students. Any suggestions that you can provide to help us achieve that goal are most welcome, and they may be sent to us in care of F. A. Davis Company, 1915 Arch Street, Philadelphia, PA 19103.

Valerie C. Scanlon
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TO THE STUDENT

This is your textbook for your course in human anatomy and physiology, a subject that is both fascinating and rewarding. That you are taking such a course says something about you. You may simply be curious as to how the human body functions or you may have a personal goal of making a contribution in one of the health care professions. Whatever your reason, this textbook will help you to be successful in your anatomy and physiology course.

The material is presented simply and concisely yet with accuracy and precision. The writing style is informal yet clear and specific; it is intended to promote your comprehension and understanding.

ORGANIZATION OF THE TEXTBOOK

To use this textbook effectively, you should know the purpose of its various parts. Each chapter is organized in the following way:

Chapter Outline—This presents the main topics in the chapter, which correspond to the major headings in the text.

Student Objectives—These summarize what you should know after reading and studying the chapter. These are not questions to be answered, but are, rather, with the chapter outline, a preview of the chapter contents.

New Terminology and Related Clinical Terminology—These are some of the new terms you will come across in the chapter. Read through these terms before you read the chapter, but do not attempt to memorize them just yet. When you have finished the chapter, return to the list and see how many terms you can define. Note those you may not be sure of and look them up. All of these terms are fully defined in the glossary.

Study Outline—At the end of the chapter, this is a concise summary of the essentials in the chapter. You may find this outline useful as a quick review before an exam.

Review Questions—These are also at the end of the chapter. Your instructor may assign them as homework. If not, the questions may be used as a self-test to evaluate your comprehension of the chapter's content. The page number(s) in parentheses following each question refer you to the page(s) in the chapter on which the content needed to answer the question can be found.

For Further Thought—The heading tells you what these questions are for: thinking. Your instructor may use these for class discussion, and, if so, please do not ever be afraid to be mistaken. Contribute, raise your hand, speak up with your best thoughts, and listen to those of others. Together you will find the answers.

OTHER FEATURES WITHIN EACH CHAPTER

Illustrations—These are an essential part of this textbook. They are intended to help you develop your own mental picture of the body and its parts and processes. You may not have thought of mental pictures as being important, but they are, and each new one you create is a major step in learning. Each illustration is referenced in the text, so you will know when to consult it. With a little concentration, you will have it in your mind for whenever you need it. You will see that each illustration has a question after the legend. These questions provide an ongoing quiz; try to answer each one as you come to it. The answers are given in Appendix G, just before the glossary.

Boxes—Discussions of clinical applications are in separate boxes in the text so that you may find them easily. Your instructor may include all or some of these as required reading. These boxes are an introduction to pathophysiology.

Bold Type—This is used whenever a new term is introduced, or when an old term is especially important. The terms in bold type are fully defined in the glossary, which includes phonetic pronunciations.

Tables—This format is used to present material in a very concise form. Some tables are summaries of text material and are very useful for a quick review. Other tables present additional material that complements the text material.

Glossary—Found at the end of the book, the glossary is your dictionary. All of the terms in bold type in the text, as well as others, are defined here. Make use of it, rather than wonder what a word means. The sooner you have a definition firmly in your mind, the sooner it is truly part of your knowledge.

To make the best use of your study time, a *Student Workbook* is available that will help you to focus your attention on the essentials in each chapter. Also included are comprehensive chapter tests to help you determine which topics you have learned thoroughly and which you may have to review. You will find it very helpful.

SOME FINAL WORDS OF ENCOURAGEMENT

Your success in this course depends to a great extent on you. Try to set aside study time for yourself every day; a little time each day is usually much more productive than trying to cram at the last minute.

Ask questions of yourself as you are studying. What kinds of questions? The simplest ones. If you are studying a part of the body such as an organ, ask yourself: What is its name? Where is it? What is it made of? What does it do? That is: name, location, structure, and function. These are the essentials. If you are studying a process, ask yourself: What is happening here? What is its purpose? That is: What is going on? And what good is it? Again, these are the essentials.

We hope this textbook will contribute to your success in this course and in your education.

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TS

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SEVENTH EDITION

ESSENTIALS OF
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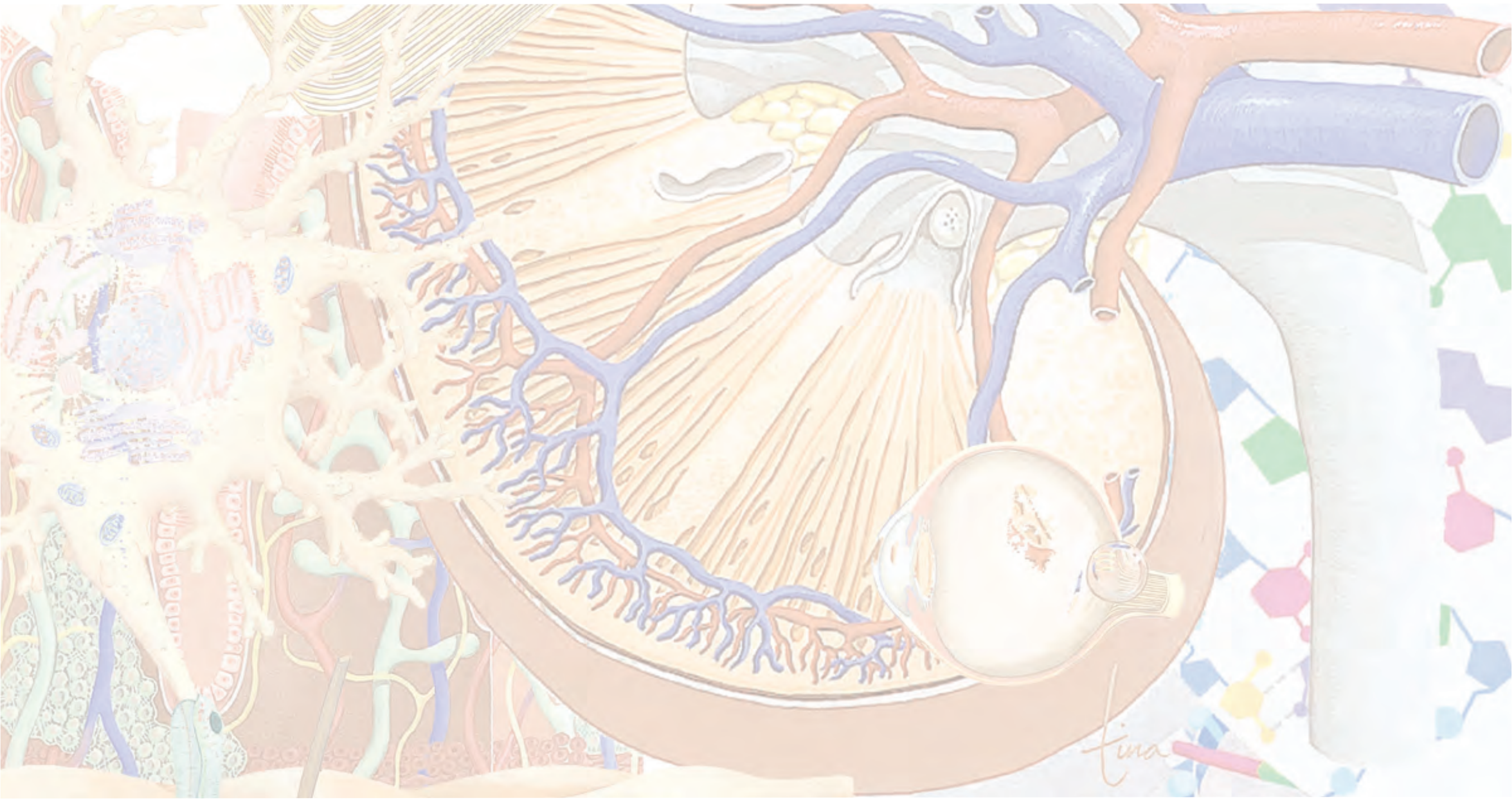

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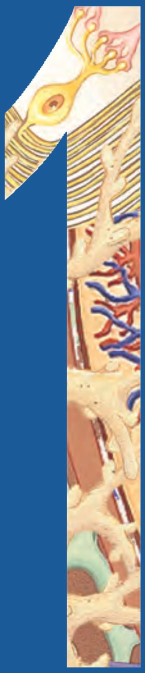

1

Organization and General Plan of the Body

STUDENT OBJECTIVES

- Define the terms *anatomy*, *physiology*, and *pathophysiology*. Use an example to explain how they are related.
- Name the levels of organization of the body from simplest to most complex, and explain each.
- Define the terms *metabolism*, *metabolic rate*, and *homeostasis*, and use examples to explain each.
- Explain how a negative feedback mechanism works and how a positive feedback mechanism differs.
- Describe the anatomic position.
- State the anatomic terms for the parts of the body.
- Use proper terminology to describe the location of body parts with respect to one another.
- Name the body cavities, their membranes, and some organs within each cavity.
- Describe the possible sections through the body or an organ.
- Explain how and why the abdomen is divided into smaller areas. Be able to name organs in these areas.

NEW TERMINOLOGY

Anatomy *(uh-**NAT**-uh-mee)*
Body cavity *(**BAH**-dee **KAV**-i-tee)*
Cell *(SELL)*
Homeostasis *(HOH-me-oh-**STAY**-sis)*
Inorganic chemicals *(**IN**-or-GAN-ik **KEM**-i-kuls)*
Meninges *(me-**NIN**-jeez)*
Metabolism *(muh-**TAB**-uh-lizm)*
Microbiota *(MY-kroh-bye-**OH**-ta)*
Microbiome *(MY-kroh-**BYE**-ohm)*
Negative feedback *(**NEG**-ah-tiv **FEED**-bak)*
Organ *(**OR**-gan)*
Organ system *(**OR**-gan **SIS**-tem)*
Organic chemicals *(or-**GAN**-ik **KEM**-i-kuls)*
Pathophysiology *(PATH-oh-FIZZ-ee-**AH**-luh-jee)*
Pericardial membranes *(PER-ee-**KAR**-dee-uhl **MEM**-brayns)*
Peritoneum-mesentery *(PER-i-toh-**NEE**-um **MEZ**-en-TER-ee)*
Physiology *(FIZZ-ee-**AH**-luh-jee)*
Plane *(PLAYN)*
Pleural membranes *(**PLOOR**-uhl **MEM**-brayns)*
Positive feedback *(**PAHS**-ah-tiv **FEED**-bak)*
Section *(**SEK**-shun)*
Tissue *(**TISH**-yoo)*

RELATED CLINICAL TERMINOLOGY

Computed tomography (CT) scan *(kom-**PEW**-ted toh-**MAH**-grah-fee SKAN)*
Diagnosis *(DYE-ag-**NOH**-sis)*
Disease *(di-**ZEEZ**)*
Magnetic resonance imaging (MRI) *(mag-**NET**-ik **REZ**-uh-nanse **IM**-ah-jing)*
Positron emission tomography (PET) *(**PAHZ**-i-tron e-**MISH**-un toh-**MAH**-grah-fee)*

*Terms that appear in **bold type** in the chapter text are defined in the glossary, which begins on page 603.*

CHAPTER OUTLINE

Levels of Organization
Chemicals
Cells
Tissues
Organs
Organ Systems
The Rest of "Us"
Metabolism and Homeostasis
Terminology and General Plan of the Body
Body Parts and Areas
Terms of Location and Position
Body Cavities and Their Membranes
Cranial and Spinal Cavities
Thoracic, Abdominal, and Pelvic Cavities
Planes and Sections
Areas of the Abdomen

BOX 1–1
Replacing Tissues and Organs

BOX 1–2
Visualizing the Interior of the Body

BOX 1–3
Watching the Brain at Work

The human body is a precisely structured container of chemicals and chemical reactions. Have you ever thought of yourself in this way? Probably not, and yet, in the strictly physical sense, that is what each of us is. The body consists of trillions of atoms in specific arrangements (the chemicals) and thousands of chemical reactions proceeding in a very orderly manner. That literally describes us, and yet it is clearly not the whole story. The keys to understanding human consciousness and self-awareness are still beyond our grasp. We do not yet know what enables us to study ourselves—no other animals do, as far as we know—but we have accumulated a great deal of knowledge about what we are made of and how it all works. Some of this knowledge makes up the course you are about to take, a course in basic human anatomy and physiology.

Anatomy is the study of body structure, which includes size, shape, composition, and perhaps even coloration. **Physiology** is the study of how the body functions. The physiology of red blood cells, for example, includes what these cells do, how they do it, and how this is related to the functioning of the rest of the body. Physiology is directly related to anatomy. For example, red blood cells contain the mineral iron in molecules of the protein called hemoglobin; this is an aspect of their anatomy. The presence of iron enables red blood cells to carry oxygen, which is their function. All cells in the body must receive oxygen in order to function properly, so the physiology of red blood cells is essential to the physiology of the body as a whole.

Pathophysiology is the study of disorders of functioning, and a knowledge of normal physiology makes such disorders easier to understand. For example, you are probably familiar with the anemia called iron-deficiency anemia. With insufficient iron in the diet, there will not be enough iron in the hemoglobin of red blood cells, and hence less oxygen will be transported throughout the body, resulting in the symptoms of the iron-deficiency disorder. This example shows the relationship among anatomy, physiology, and pathophysiology.

The purpose of this text is to enable you to gain an understanding of anatomy and physiology with an emphasis on normal structure and function. Many examples of pathophysiology have been included, however, to illustrate the relationship of **disease** to normal physiology and to describe some of the procedures used in the **diagnosis** of disease. Many of the examples are clinical applications that will help you begin to apply what you have learned. Your knowledge of anatomy and physiology will become the basis for your further study in the health professions.

LEVELS OF ORGANIZATION

The human body is organized into structural and functional levels of increasing complexity. Each higher level incorporates the structures and functions of the previous level, as you will see. We will begin with the simplest level, which is the chemical level, and proceed to cells, tissues, organs, and organ systems. All of the levels of organization are depicted in Fig. 1–1.

CHEMICALS

Recall that the body is a container of chemicals. The chemicals that make up the body may be divided into two major categories: inorganic and organic. **Inorganic chemicals** are usually simple molecules made of one or two elements other than carbon (with a few exceptions). Examples of inorganic chemicals are water (H_2O); oxygen (O_2); one of the exceptions, carbon dioxide (CO_2); and minerals such as iron (Fe) in hemoglobin, sodium (Na) in the salt sodium chloride that makes tears salty, and calcium (Ca) in the calcium salts that make bones hard. **Organic chemicals** are often very complex and always contain the elements carbon and hydrogen. In the category of organic chemicals are carbohydrates, fats, proteins, and nucleic acids. The chemical organization of the body is the subject of Chapter 2.

CELLS

The smallest living units of structure and function are **cells**, and the human body consists of more than 200 different types of cells. Another way to think of the body is as a city of cells. Just as a large city has millions of people with many different jobs, the body contains trillions of cells that perform more than 200 jobs. Despite these different functions, human cells have certain structural similarities. Each type of cell is made of chemicals and carries out specific chemical reactions. Cell structure and function are discussed in Chapter 3.

TISSUES

A **tissue** is a group of cells with similar structure and function. Just as in a city certain groups of individuals work together (in the fire department, for example) to keep the city functioning, groups of similar cells work together in the body. There are four groups of tissues:

Epithelial tissues—cover or line body surfaces; some are capable of producing secretions with specific functions

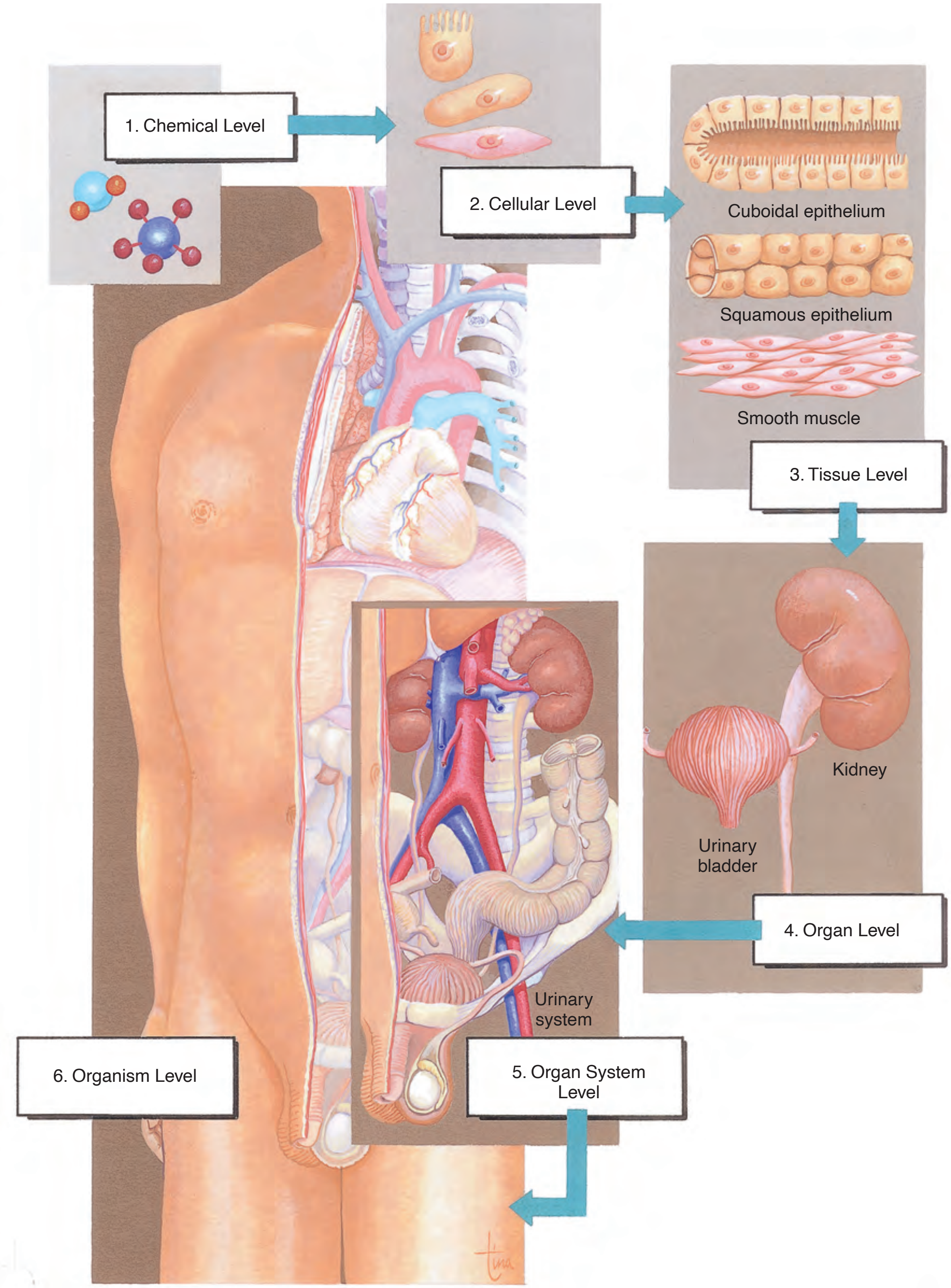

Figure 1–1 Levels of structural organization of the human body, depicted from the simplest (chemical) to the most complex (organism). The organ system shown here is the urinary system.

QUESTION: What other organ system seems to work directly with the urinary system?

The outer layer of the skin and sweat glands are examples of epithelial tissues. Internal epithelial tissues include the walls of capillaries (squamous epithelium) and the kidney tubules (cuboidal epithelium), as shown in Fig. 1–1.

Connective tissues—connect and support parts of the body; some transport or store materials. Blood, bone, cartilage, and adipose tissue are examples of this group.

Muscle tissues—are specialized for contraction, which brings about movement. Our skeletal muscles and the heart are examples of muscle tissue. In Fig. 1–1, you see smooth muscle tissue, which is found in organs such as the urinary bladder and stomach.

Nerve tissues—specialized to generate and transmit electrochemical impulses that regulate body functions. The brain and the optic nerves are examples of nerve tissue.

The types of tissues in these four groups, as well as their specific functions, are the subject of Chapter 4.

ORGANS

An **organ** is a group of tissues precisely arranged so as to accomplish specific functions. Examples of organs are the kidneys, individual bones, the liver, the lungs, and the stomach. The kidneys contain several kinds of epithelial, or surface tissues, for their work of absorption. The stomach is lined with epithelial tissue that secretes gastric juice for digestion, especially of proteins. Smooth muscle tissue in the wall of the stomach contracts to mix food with gastric juice and propel it to the small intestine. Nerve tissue carries impulses that increase or decrease the contractions of the stomach. An organ may be considered a "cooperation of tissues," in which the whole is the anatomic sum of its parts, and much more than the physiologic sum. None of the tissues of the kidney can remove waste products from the blood by itself, but the functioning of all of the kidney tissues does so. Similarly, none of the tissues of the stomach can by itself begin the digestion of protein, but the stomach as a whole can (see Box 1–1: Replacing Tissues and Organs).

ORGAN SYSTEMS

An **organ system** is a group of organs that all contribute to a particular function. Examples are the urinary system, the digestive system, and the respiratory system. In Fig. 1–1 you see the urinary system, which consists of the kidneys, ureters, urinary bladder, and urethra. These organs all contribute to the formation and elimination of urine.

As a starting point, Table 1–1 lists the organ systems of the human body with their general functions and some representative organs, and Fig. 1–2 depicts all of the organ systems. Many of these are already familiar to you. Some organs are part of two organ systems; the pancreas, for example, is both a digestive organ and an endocrine organ, and the diaphragm is part of both the muscular system and the respiratory system. All of the organ systems make up an individual person, and all of them function together; that is, they are interdependent. For now, a few examples will give you an idea of the many interactions among the systems. All cells in the body require oxygen. The respiratory system obtains oxygen from the atmosphere, and the circulatory system distributes the oxygen. All cells need nutrients. The digestive system gets the nutrients, and the circulatory system distributes them. All cells produce waste products. The circulatory system collects the waste products, and the urinary system eliminates them from the blood. The balance of this text discusses each system and its interactions with other systems in more detail.

THE REST OF "US"

We are not alone. Every human being lives with an enormous population of bacteria and other microorganisms, our **microbiota**. It is estimated that the total bacteria that reside on us or inside us, with the most in the intestines, outnumber our own cells about 10 to 1. An older name for this population is **normal flora** (or resident flora, see Table 22–1 for their distribution), and different people have different proportions of the hundreds of species that make us their home. Each site on or inside the body that has bacteria is considered a small ecosystem called a **microbiome.** We have known for years that some intestinal bacteria produce vitamins that we absorb, especially vitamin K. We have also known that these bacteria, in their usual body site (surface of the skin, oral cavity, the vagina in women, among other microbiomes), help to prevent the growth of pathogens. This knowledge has been used lately to try to help those with antibiotic-resistant *Clostridium difficile* intestinal infections, and some people have been cured by "fecal transplants" (in capsule form) of intestinal bacteria from a healthy family member.

Box 1–1 | REPLACING TISSUES AND ORGANS

Blood transfusions are probably the most familiar and frequent form of "replacement parts" for people. Blood is a tissue and, when properly typed and cross-matched (blood types will be discussed in Chapter 11), may safely be given to someone with a blood type that is the same or compatible.

Organs, however, are much more complex structures. When a patient receives an organ transplant, there is always the possibility of rejection (destruction) of the organ by the recipient's immune system (Chapter 14). With the discovery and use of more effective immune-suppressing medications, however, the success rate for many types of organ transplants has increased. Organs that may be transplanted include the corneas, the kidneys, the heart, the liver, and the lungs.

The skin is also an organ, but skin transplanted from another person will not survive very long. Several kinds of artificial skin are now available to temporarily cover large areas of damaged skin. Patients with severe burns, for example, will eventually need skin grafts from their own unburned skin to form permanent new skin over the burn sites. It is possible to "grow" a patient's skin in laboratory culture so that a small patch of skin may eventually be used to cover a large surface. Other cells grown in culture include cartilage, bone, pancreas, liver, and skeletal muscle. Such implants may reduce or eliminate the need for human donors. Tissue engineering is also being used to create tracheas, arteries, urinary bladders, and heart valves.

Many artificial replacement parts have also been developed. These are made of plastic or metal and are not rejected as foreign by the recipient's immune system. Damaged heart valves or sections of arteries may be replaced by grafts made of synthetic materials. Artificial joints are available for every joint in the body, as is artificial bone for reconstructive surgery. Cochlear implants are tiny instruments that convert sound waves to electrical impulses the brain can learn to interpret and have provided some sense of hearing for people with certain types of deafness. A corneal implant is available for a person with age-related macular degeneration (see Chapter 9), in which central vision has been lost. The implant can enable the person to recognize faces and to read large-print books. Work is also progressing on devices that help damaged hearts pump blood more efficiently and on small, self-contained artificial hearts.

Although these new techniques and artificial parts have great promise, we must be realistic: They are very expensive and most will not become the standard of care or be in widespread use for many years.

Recent research suggests that by fermenting the food residues that we do not digest (often fiber, the complex carbohydrates of plants), the intestinal bacteria help nourish the epithelial cells that form the intestinal lining. Not only does this keep the lining intact and prevent leakage of intestinal contents into the tissues of the body, but it also helps suppress inflammation, which in excess can be damaging. Other researchers propose that our microbiota help the immune system to establish itself and contribute to the ability of our white blood cells to distinguish between "self" and "non-self." This is especially important for limiting the development of allergies (mistaken immune responses) and their potentially serious consequences such as asthma. Still other studies are investigating the contribution our microbiota make to weight loss or gain. This is all good but is not the whole story.

The presence of our microbiota has drawbacks as well. Not all bacterial products are beneficial to humans. Some, if absorbed, may be harmful, as is one (made from a chemical called carnitine found in red meat such as beef) that may contribute to heart disease. The total number of genes of all of these bacteria is estimated to be several million (in comparison, the genes of a human cell total about 22,000). Most of the bacterial products

Table 1–1 | THE ORGAN SYSTEMS

SYSTEM	FUNCTIONS	ORGANS*
Integumentary	■ Is a barrier to pathogens and chemicals ■ Prevents excessive water loss	skin, subcutaneous tissue
Skeletal	■ Supports the body ■ Protects internal organs and red bone marrow ■ Provides a framework to be moved by muscles	bones, ligaments
Muscular	■ Moves the skeleton ■ Produces heat	muscles, tendons
Nervous	■ Interprets sensory information and decides how to use it ■ Regulates body functions such as movement by means of electrochemical impulses	brain, spinal cord, nerves, eyes, ears
Endocrine	■ Regulates body functions such as growth and reproduction by means of hormones ■ Regulates day-to-day metabolism by means of hormones	thyroid gland, pituitary gland, ovaries or testes, pancreas
Circulatory	■ Transports oxygen and nutrients to tissues and removes waste products	heart, blood, arteries, veins
Lymphatic	■ Returns tissue fluid to the blood ■ Destroys pathogens that enter the body and provides immunity	spleen, lymph nodes, thymus gland
Respiratory	■ Exchanges oxygen and carbon dioxide between the air and blood	lungs, trachea, larynx, diaphragm
Digestive	■ Changes food into simple chemicals that can be absorbed and used by the body	stomach, colon, liver, pancreas
Urinary	■ Removes waste products from the blood ■ Regulates volume and pH of blood and tissue fluid	kidneys, urinary bladder, urethra
Reproductive	■ Produces eggs or sperm ■ *In women*, provides a site for the developing embryo-fetus	Female: ovaries, uterus Male: testes, prostate gland

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*These are simply representative organs, not an all-inclusive list.

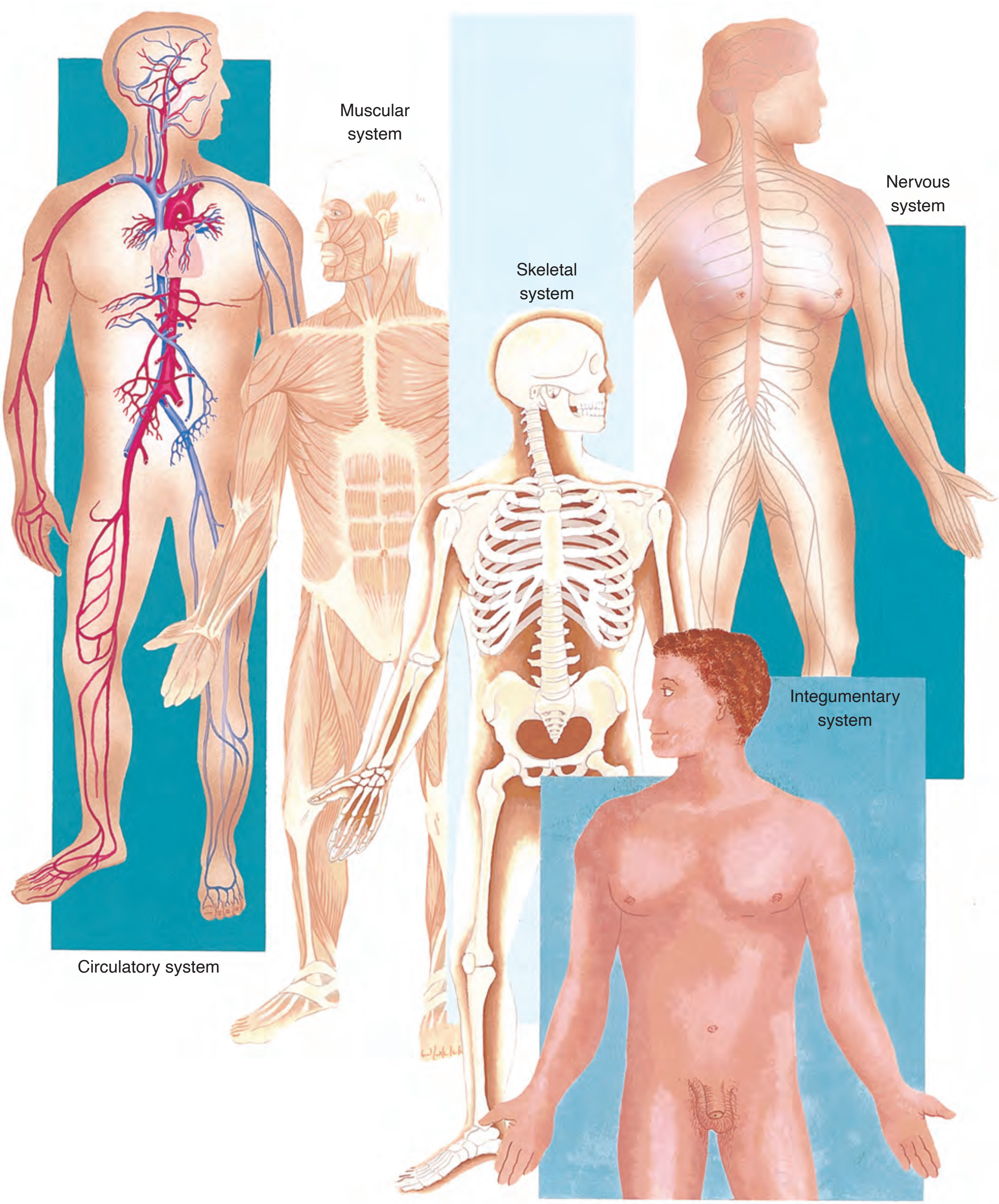


Figure 1–2 Organ systems. Compare the depiction of each system to its description in Table 1–1.

QUESTION: Name at least one organ shown in each system.

Continued

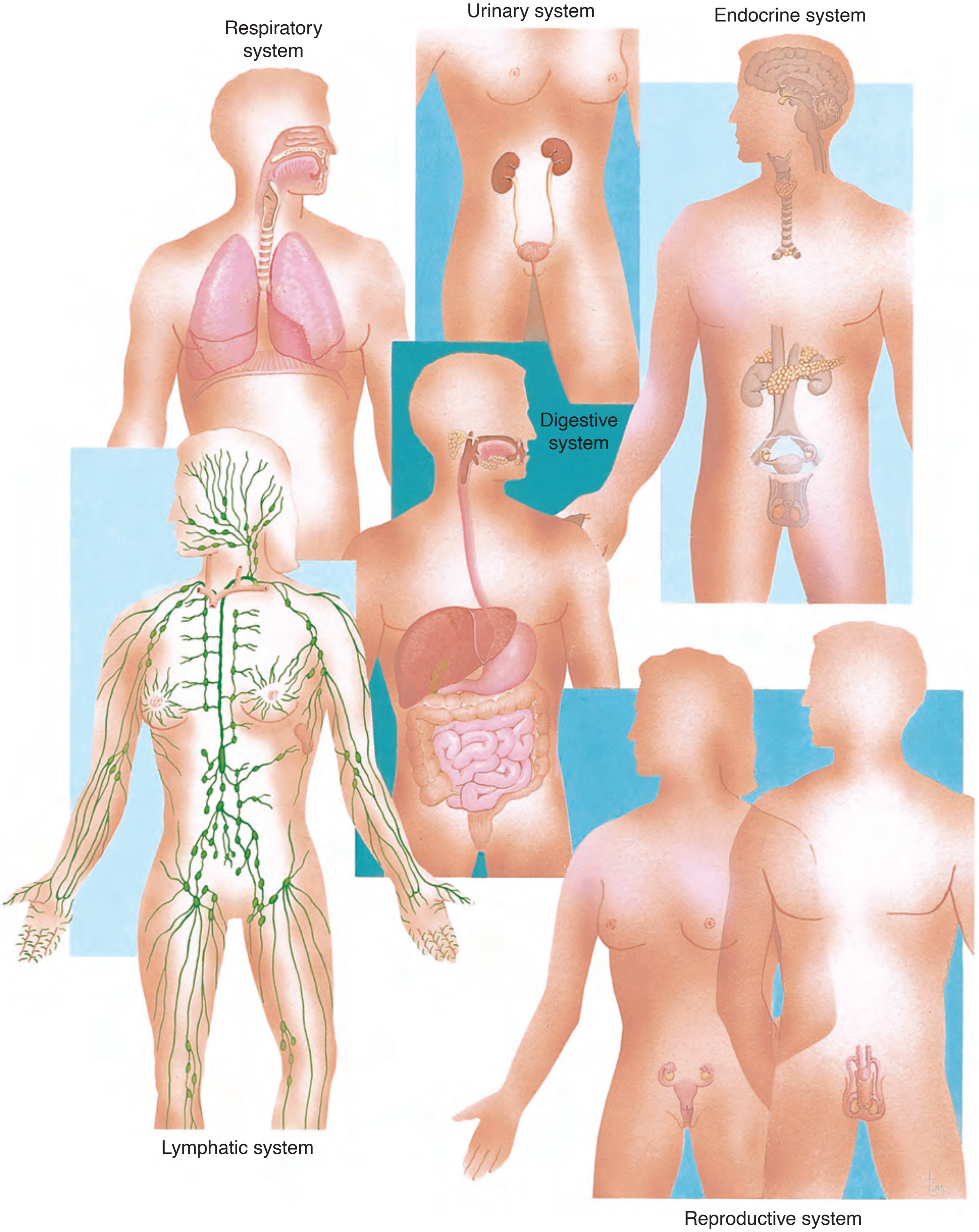


Figure 1–2—cont'd

of these genes have yet to be discovered, and much more work remains to be done before we truly understand the complex relationship we have with our microbiota.

METABOLISM AND HOMEOSTASIS

Metabolism is a collective noun; it is all of the chemical reactions and physical processes that take place within the body. Metabolism includes growing, repairing, reacting, and reproducing—all the characteristics of life. The pumping of the heart, the digestion of food in the stomach, the diffusion of gases in the lungs and tissues, and the production of energy in each cell of the body are just a few of the thousands of aspects of metabolism. *Metabolism* comes from a Greek word meaning "change," and the body is always changing in visible ways (walking down the street), microscopic ways (cells dividing in the skin to produce new epidermis) and submicroscopic or molecular ways (RNA and enzymes constructing new proteins). A related concept, **metabolic rate**, is most often used to mean the speed at which the body produces energy and heat or, put another way, energy production per unit of time, such as 24 hours. Metabolic rate, therefore, is one aspect of metabolism.

A person who is in good health may be said to be in a state of **homeostasis**. Good health is a product of normal metabolism, and homeostasis reflects the ability of the body to maintain a relatively stable metabolism and to function normally despite many constant changes. The changes that are part of normal metabolism may be internal or external, and the body must respond appropriately.

Eating breakfast, for example, brings about an internal change. Suddenly there is food in the stomach, and something must be done with it. What happens? The food is digested or broken down into simple chemicals that the body can use. The protein in a hard-boiled egg is digested into amino acids, its basic chemical building blocks; these amino acids can then be used by the cells of the body to produce their own specialized proteins.

An example of an external change is a rise in environmental temperature. On a hot day, the body temperature would also tend to rise. However, body temperature must be kept within its normal range of about 97° to 99°F (36° to 38°C) to support normal functioning. What happens? One of the body's responses to the external temperature rise is to increase sweating so that excess body heat can be lost by the evaporation of sweat on the surface of the skin. This response, however, may bring about an undesirable internal change, dehydration. What happens? As body water decreases, we feel the sensation of thirst, and we drink fluids to replace the water lost in sweating. Notice that when certain body responses occur, they reverse the event that triggered them. In the preceding example a rising body temperature stimulates increased sweating, which lowers body temperature, which in turn decreases sweating. Unnecessary sweating that would be wasteful of water is prevented. This is an example of a **negative feedback mechanism**, in which the body's response reverses the stimulus (in effect, turning it off for a while) and keeps some aspect of the body metabolism within its normal range.

Look at Fig. 1–3 for another negative feedback mechanism, one in which the hormone thyroxine regulates the metabolic rate of the body. As metabolic rate decreases, the hypothalamus (a part of the brain) and the pituitary gland detect this decrease and secrete hormones to stimulate the thyroid gland (on the front of the neck, just below the larynx) to secrete the hormone thyroxine. Thyroxine stimulates the cellular enzyme systems that produce energy from food, which increases the metabolic rate. The rise in energy and heat production is detected by the brain and pituitary gland. They then decrease secretion of their hormones, which in turn inhibits any further secretion of thyroxine until the metabolic rate decreases again. Metabolic rate does rise and fall, but it is kept within normal limits.

You may be wondering if there is such a thing as a positive feedback mechanism. There is, but such mechanisms are rare in the body and quite different from negative feedback mechanisms. In a **positive feedback mechanism**, the response to the stimulus does not stop or reverse the stimulus, but instead keeps the sequence of events going until it is interrupted by some external event. A good example is childbirth, in which the sequence of events, simply stated, is as follows: Stretching of the uterine cervix stimulates secretion of the hormone oxytocin by the posterior pituitary gland. Oxytocin stimulates contraction of the uterine muscle, which causes more stretching of the cervix as the baby is pushed through, which stimulates the secretion of more oxytocin and, hence, more contractions. The mechanism stops with the delivery of the baby and the placenta. This is the "brake," the interrupting event.

Any positive feedback mechanism requires an external "brake," something to interrupt it. Blood clotting is such a mechanism, and without external controls, clotting may become a vicious cycle of clotting and more clotting, doing far more harm than good (clotting is discussed in Chapter 11). Inflammation, the body's response to

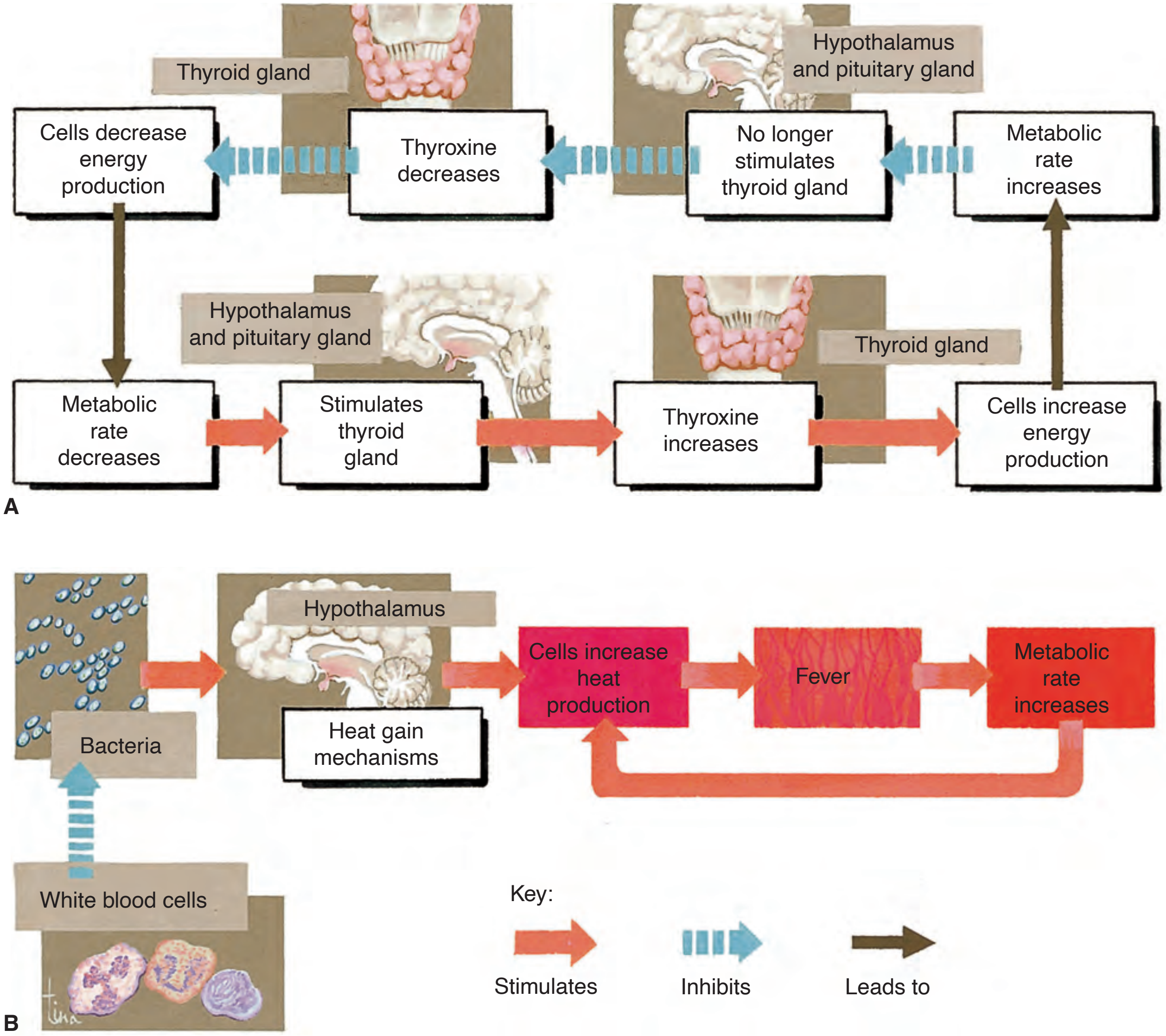


Figure 1–3 Feedback mechanisms. (**A**) The negative feedback mechanism of regulation of metabolic rate by thyroxine. (**B**) The positive feedback mechanism triggered by a fever. See text for description.

QUESTION: For each mechanism, where is the source of the "brake" or inhibition?

damage of any sort, is beneficial and necessary for tissue repair to begin, but the process may evolve into a cycle of damage and more damage, and it requires an external control to stop it. The rise of a fever may also trigger a positive feedback mechanism. Notice in Fig. 1–3 that bacteria have affected the body's thermostat in the hypothalamus and caused a fever. The rising body temperature increases the metabolic rate, which increases body temperature even more, becoming a cycle. Where is the inhibition, the brake? For this infection, the brake is white blood cells destroying the bacteria that caused the fever. An interruption from outside the cycle is necessary.

It is for this reason, because positive feedback mechanisms have the potential to be self-perpetuating and cause harm, that they are rare in the body.

Negative feedback mechanisms, however, contain their own brakes, in that inhibition is a natural part of these cycles, and the body has many such mechanisms. The secretion of most hormones (Chapter 10) is regulated by negative feedback mechanisms. The regulation of heart rate (Chapter 12) and of blood pressure (Chapter 13) involves several negative feedback mechanisms. The result of all of these mechanisms working together is that all aspects of body functioning, that is, of metabolism, are kept within normal limits, a steady state or equilibrium. This is homeostasis.

In the chapters to come, you will find many more examples of homeostasis. As you continue your study of the human body, keep in mind that the proper functioning of each organ and organ system contributes to homeostasis. Keep in mind as well that what we call the normal values of metabolism are often ranges, not single numbers. Recall that normal body temperature is a range: 97° to 99°F (36° to 38°C). Normal pulse rate, another example, is 60 to 80 beats per minute; a normal respiratory rate is 12 to 20 breaths per minute. Variations within the normal range are part of normal metabolism.

TERMINOLOGY AND GENERAL PLAN OF THE BODY

As part of your course in anatomy and physiology, you will learn many new words or terms. At times you may feel that you are learning another language, and indeed you are. Each term has a precise meaning, which is understood by everyone else who has learned the language. Mastering the terminology of your profession is essential to communicating effectively with your coworkers and your future patients. Although the number of new terms may seem a bit overwhelming at first, you will find that using these terms will soon become second nature to you.

The terminology presented in this chapter will be used throughout the text in the discussion of the organ systems. This will help to reinforce the meanings of these terms and will transform these new words into knowledge.

BODY PARTS AND AREAS

Each of the terms listed in Table 1–2 and shown in Fig. 1–4 refers to a specific part or area of the body. For example, the term *femoral* always refers to the thigh, and *brachial* always refers to the upper arm. The femoral

Table 1–2 | **DESCRIPTIVE TERMS FOR BODY PARTS AND AREAS**

TERM	DEFINITION (REFERS TO)	TERM	DEFINITION (REFERS TO)
Antebrachial	forearm	Gluteal	buttocks
Antecubital	front of elbow	Hepatic	liver
Axillary	armpit	Iliac	hip
Brachial	upper arm	Inguinal	groin
Buccal (oral)	mouth	Lumbar	small of back
Cardiac	heart	Mammary	breast
Cervical	neck	Nasal	nose
Cranial	head	Occipital	back of head
Cutaneous	skin	Orbital	eye
Deltoid	shoulder	Parietal	crown of head
Femoral	thigh	Patellar	kneecap
Frontal	forehead	Pectoral	chest
Gastric	stomach	Pedal	foot

Continued

Table 1–2 | **DESCRIPTIVE TERMS FOR BODY PARTS AND AREAS—cont'd**

TERM	DEFINITION (REFERS TO)	TERM	DEFINITION (REFERS TO)
Perineal	pelvic floor	Scapular	shoulder blade
Plantar	sole of foot	Sternal	breastbone
Popliteal	back of knee	Temporal	side of head
Pulmonary	lungs	Umbilical	navel
Renal	kidney	Volar (palmar)	palm
Sacral	base of spine		

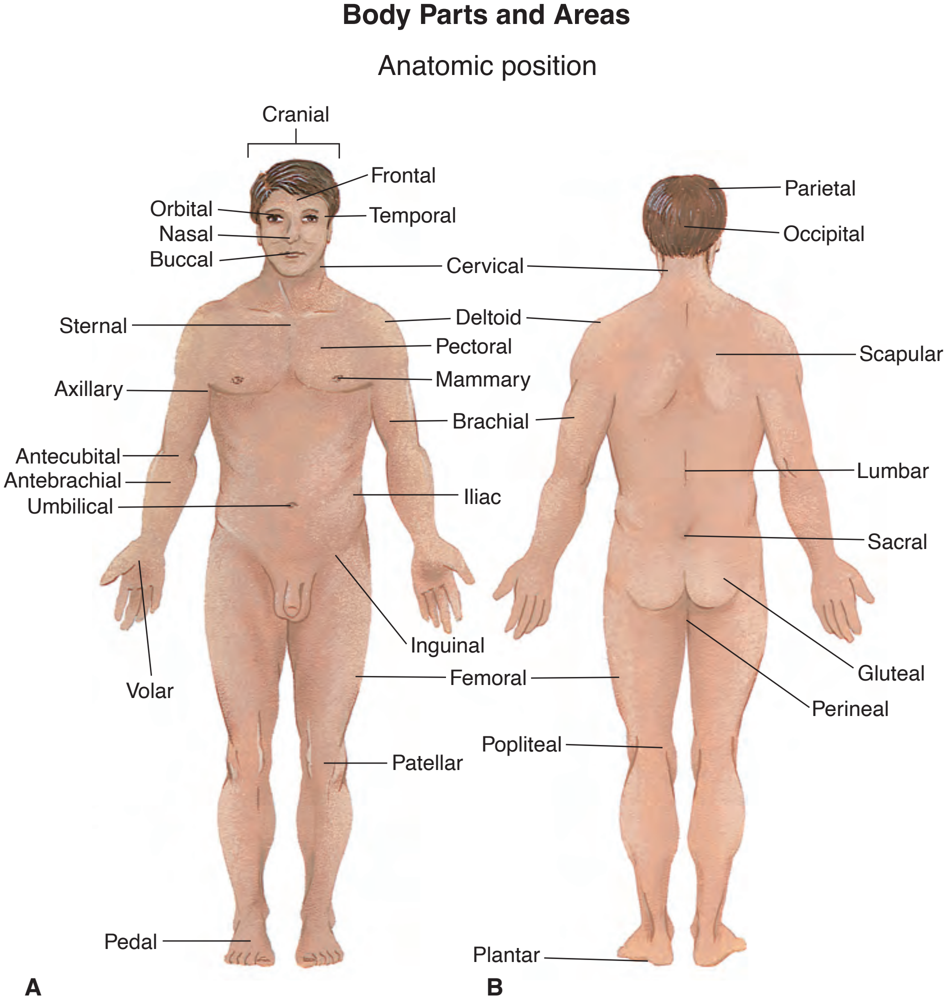


Figure 1–4 Body parts and areas. The body is shown in anatomic position. (**A**) Anterior view. (**B**) Posterior view. (Compare with Table 1–2.)

QUESTION: Name a body area that contains a bone with a similar name. Can you name two more?

artery is a blood vessel that passes through the thigh, and the quadriceps femoris is a large muscle group of the thigh. The brachial artery passes through the upper arm, and the biceps brachii and triceps brachii are the major muscles of the upper arm.

Another example is *pulmonary*, a term that always refers to the lungs, as in pulmonary artery, pulmonary edema, and pulmonary embolism. Although you may not know the exact meaning of each of these terms now, you do know that each has something to do with the lungs.

TERMS OF LOCATION AND POSITION

When describing relative locations, the body is always assumed to be in anatomic position: standing upright facing forward, arms at the sides with palms forward, and the feet slightly apart. The terms of location are listed in Table 1–3, with a definition and example for each. As you read each term, find the body parts used as examples in Figs. 1–4 and 1–5. Notice also that these are pairs of terms and that each pair is a set of opposites. This will help you recall the terms and their meanings.

BODY CAVITIES AND THEIR MEMBRANES

The closed cavities of the body are found in the skull, the vertebral column, and the trunk; each contains specific organs and membranes. These cavities are the cranial, spinal, thoracic, abdominal, and pelvic, and they are shown in Fig. 1–5.

Cranial and spinal cavities

The cranial and spinal cavities contain the central nervous system and are completely enclosed by protective bone. These two cavities are continuous; that is, no wall or

Table 1–3 | **TERMS OF LOCATION AND POSITION**

TERM	DEFINITION	EXAMPLE
Superior	above, or higher	The heart is superior to the liver.
Inferior	below, or lower	The liver is inferior to the lungs.
Anterior	toward the front	The chest is on the anterior side of the body.
Posterior	toward the back	The lumbar area is posterior to the umbilical area.
Ventral	toward the front	The mammary area is on the ventral side of the body.
Dorsal	toward the back	The buttocks are on the dorsal side of the body.
Medial	toward the midline	The heart is medial to the lungs.
Lateral	away from the midline	The shoulders are lateral to the neck.
Internal	within, or interior to	The brain is internal to the skull.
External	outside, or exterior to	The ribs are external to the lungs.
Superficial	toward the surface	The skin is the most superficial organ.
Deep	within, or interior to	The deep veins of the legs are surrounded by muscles.
Central	the main part	The brain is part of the central nervous system.
Peripheral	extending from the main part	Nerves in the arm are part of the peripheral nervous system.
Proximal	closer to the origin	The knee is proximal to the foot.
Distal	farther from the origin	The palm is distal to the elbow.
Parietal	pertaining to the wall of a cavity	The parietal pleura lines the chest cavity.
Visceral	pertaining to the organs within a cavity	The visceral pleura covers the lungs.

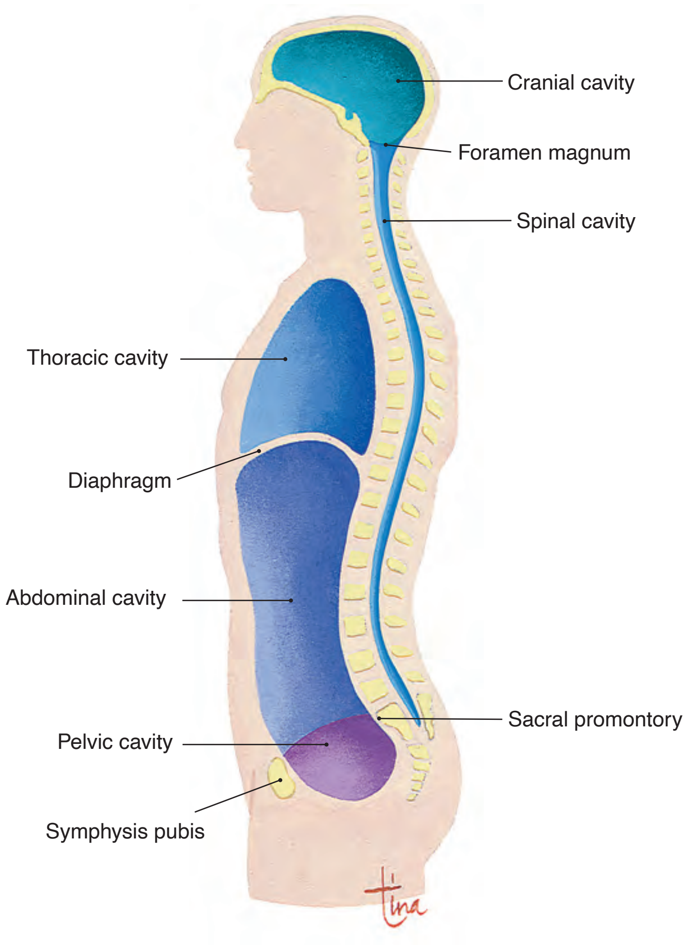


Figure 1–5 Body cavities (lateral view from the left side).

QUESTION: Which of these cavities are surrounded by bone?

boundary separates them. The cranial cavity is formed by the skull and contains the brain. The spinal (or vertebral) cavity is formed by the backbone (vertebral column or spine) and contains the spinal cord. The membranes that line these cavities and cover the brain and spinal cord are called the **meninges**.

Thoracic, Abdominal, and Pelvic Cavities

The thoracic, abdominal, and pelvic cavities are within the trunk of the body, and their contents are at least partially protected by bone. The thoracic (or chest) cavity is the most superior and is separated from the abdominal cavity below by the diaphragm. The diaphragm is a large, dome-shaped respiratory muscle. It has openings for the esophagus and for large blood vessels but otherwise is a wall between the thoracic and abdominal cavities. The pelvic cavity is the most inferior and may be considered a subdivision of the abdominal cavity (there is no wall between the two) or as a separate cavity.

Organs in the **thoracic cavity** include the heart and lungs. The membranes of the thoracic cavity are serous membranes called the **pleural membranes**. The parietal pleura lines the chest wall, and the visceral pleura covers the lungs. The heart has its own set of serous membranes called the **pericardial membranes**. The parietal pericardium lines the fibrous pericardial sac, and the visceral pericardium covers the heart muscle.

Organs in the **abdominal cavity** include the liver, the stomach, and the intestines. The membranes of the abdominal cavity are also serous membranes called the peritoneum and mesentery. The **peritoneum** is the membrane that lines the entire abdominal wall, and the **mesentery** (or visceral peritoneum) is the continuation of this membrane, folded around and covering the outer surfaces of the abdominal organs.

The **pelvic cavity** is inferior to the abdominal cavity. Although the peritoneum does not line the pelvic cavity, it covers the free surfaces of several pelvic organs. Within the pelvic cavity are the urinary bladder and reproductive organs such as the uterus in women and the prostate gland in men.

PLANES AND SECTIONS

When internal anatomy is described, the body, or an organ, is often cut or sectioned in a specific way so as to make particular structures easily visible. A **plane** is an imaginary flat surface that separates two portions of the body or an organ. These planes and **sections** are shown in Fig. 1–6.

Frontal (coronal) section—a plane from side to side separates the body into front and back portions.

Sagittal section—a plane from front to back separates the body into right and left portions. A midsagittal sectio creates equal right and left halves

Cross-section—a plane perpendicular to the long axis of an organ. A cross-section of the small intestine (which is a tube) would look like a circle with the cavity of the intestine in the center.

Longitudinal section—a plane along the long axis of an organ. A longitudinal section of the intestine is shown in Fig. 1–6B, and a frontal section of the femur (thigh bone) would also be a longitudinal section (see Fig. 6–1 in Chapter 6).

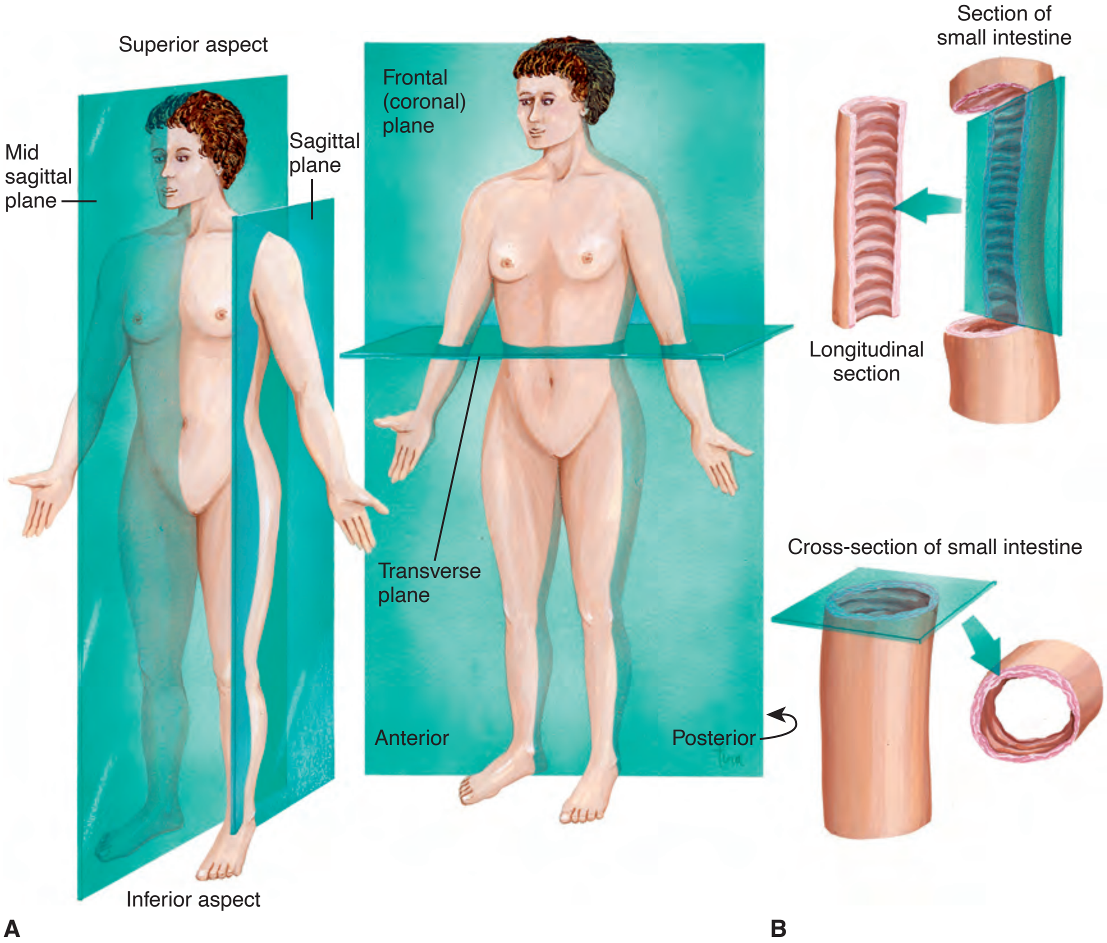


Figure 1–6 (**A**) Planes and sections of the body. (**B**) Cross-section and longitudinal section of the small intestine.

QUESTION: What other organs would have sections that look like those of the small intestine?

Continued

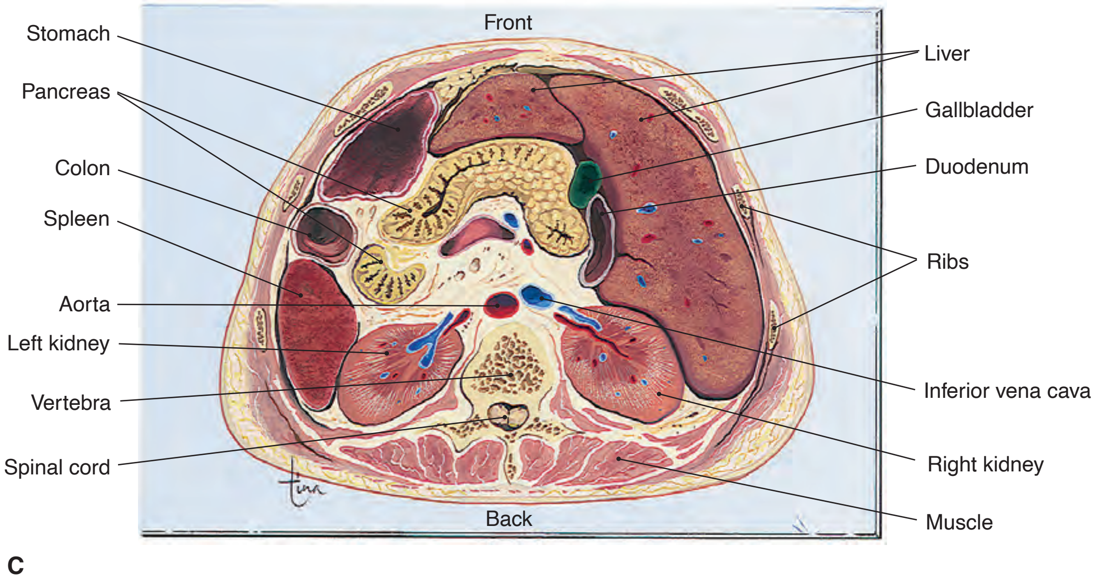


Figure 1–6—cont'd (**C**) Transverse section through the upper abdomen.

Transverse section—a horizontal plane separates the body (or a part) into upper and lower portions. Look at part C of Fig. 1–6; this is a transverse section of the upper abdomen. If you are looking at this picture with the book in front of you, the body in the picture is oriented just the way yours is. The anterior or front is a the top of the illustration, away from you. Place your right hand at the lower edge of your rib cage; that is where this section is taken. Notice all the organs at this level and how they "fit" with one another in the ab dominal cavity. Find the aorta; this is a main blood vessel and must be protected. Where is it? Right in front of the backbone, almost in the center of the body, very well protected.

Many pictures in later chapters will be sectional views of organs or body parts. Such sections are often very helpful in learning the spatial relationship of organs or other kinds of parts to one another (see also Box 1–2: Visualizing the Interior of the Body and Box 1–3: Watching the Brain at Work).

AREAS OF THE ABDOMEN

The abdomen is a large area of the lower trunk of the body. If a patient reported abdominal pain, the physician or nurse would want to know more precisely where the pain was. To determine this, the abdomen can be divided into smaller regions or areas, which are shown in Fig. 1–7.

Quadrants—a transverse plane and a midsagittal plane that cross at the umbilicus divide the abdomen into four quadrants. Clinically, this is probably the division used more frequently. The pain of gallstones migh then be described as in the right upper quadrant.

Nine areas—two transverse planes and two sagittal planes divide the abdomen into nine areas:

Upper areas—above the lower level of the rib cartilages are the left hypochondriac, epigastric, and righ hypochondriac.

Middle areas—the left lumbar, umbilical, and righ lumbar.

Lower areas—below the level of the top of the pelvic bone are the left iliac, hypogastric, and right iliac.

These divisions are often used in anatomic studies to describe the location of organs. The liver, for example, is located in the epigastric and right hypochondriac areas.

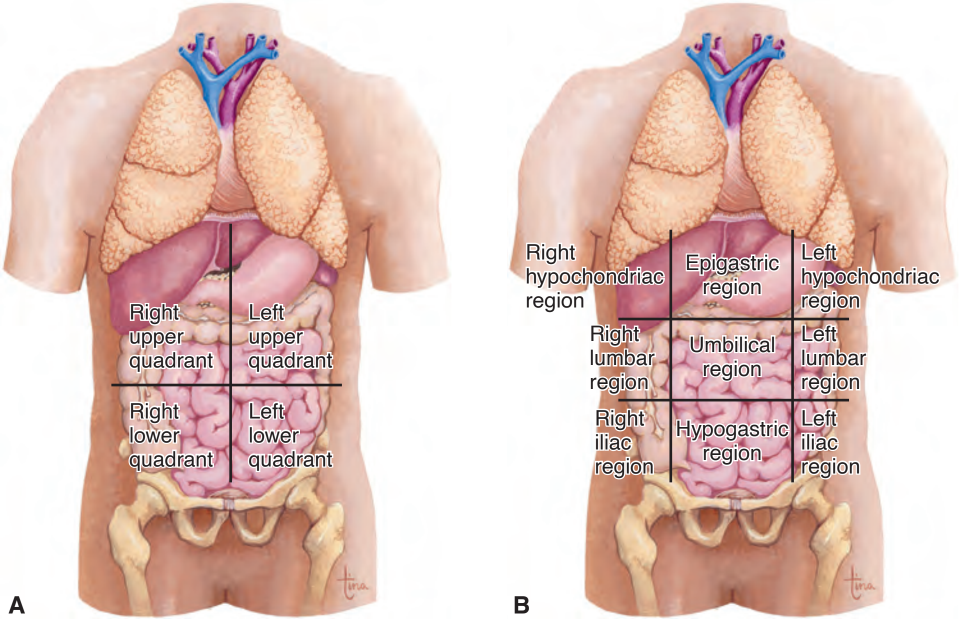


Figure 1–7 Areas of the abdomen. (**A**) Four quadrants. (**B**) Nine regions.

QUESTION: Are there any organs found in all four abdominal quadrants?

Box 1–2 | VISUALIZING THE INTERIOR OF THE BODY

Imaging technologies can often replace exploratory surgery as diagnostic tools. Although expensive, these tools provide great benefits to patients: Highly detailed images of the body are obtained without the risks of surgery and with virtually no discomfort in the procedures themselves.

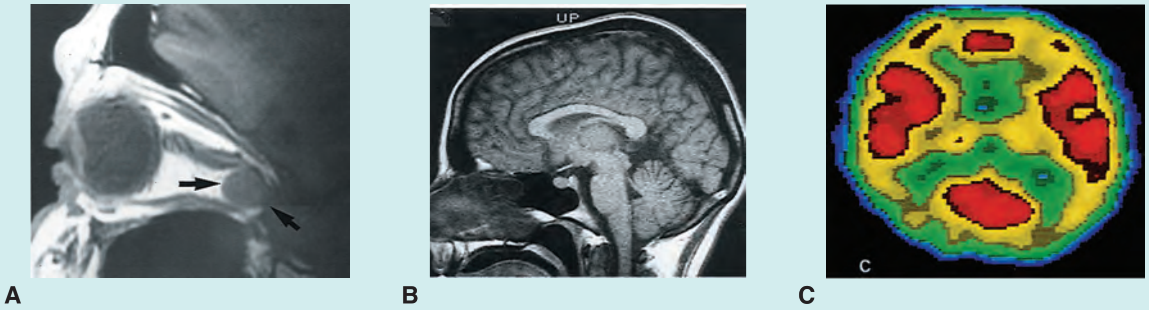
Computed tomography (**CT**) **scanning** uses a narrowly focused x-ray beam that circles rapidly around the body. A detector then measures how much radiation passes through different tissues, and a computer constructs an image of a thin slice through the body. Several images may be made at different levels—each takes only a few seconds—to provide a more complete picture of an organ or part of the body. The images are much more detailed than are those produced by conventional x-rays (Box Figure 1–A, part A).

Magnetic resonance imaging (**MRI**) is especially useful for visualizing soft tissues, including the brain, spinal cord, and individual nerves. The patient is placed inside a strong magnetic field, and the body's tissues are pulsed with radio waves. Because each tissue has different proportions of various atoms, which resonate or respond differently, each tissue emits a characteristic signal. A computer then translates these signals into an image (part B).

Positron emission tomography (**PET**) scanning creates images that depict the rates of physiologic processes such as blood flow, oxygen usage, or glucose metabolism. The comparative rates are depicted by colors: Red represents the highest rate, followed by yellow, then green, and finally blue, representing the lowest rate (part C).

Continued

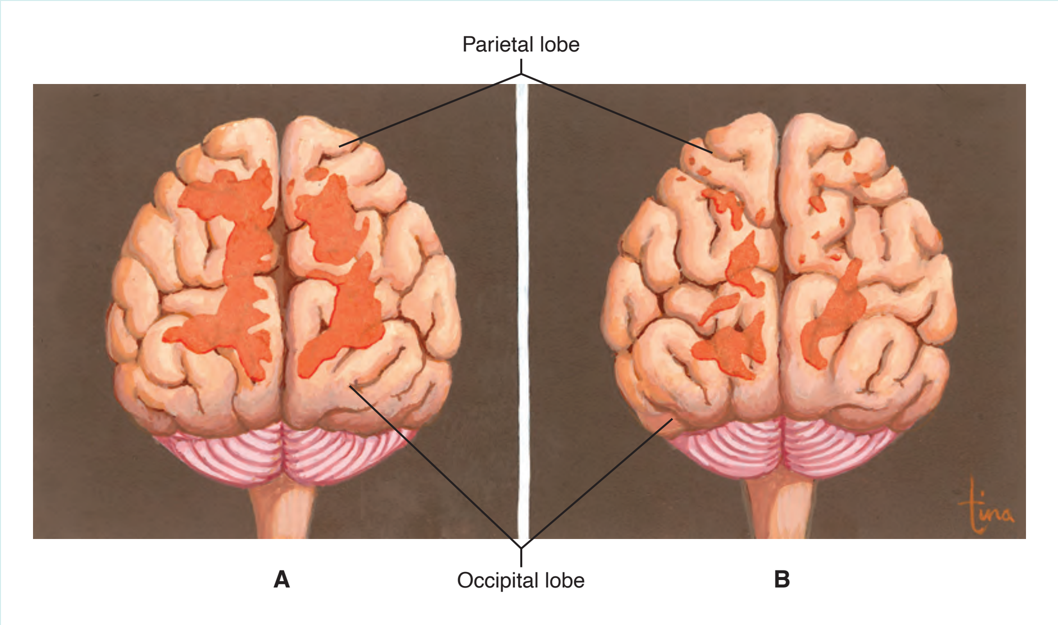
Box 1–2 | VISUALIZING THE INTERIOR OF THE BODY *(Continued)*



Box Figure 1–A Imaging techniques. (**A**) CT scan of eye in lateral view, showing a tumor *(arrow)* below the optic nerve. (**B**) MRI of midsagittal section of head (compare with Figs. 8–6 in Chapter 8 and 15–1 in Chapter 15). (**C**) PET scan of brain in transverse section (frontal lobes at top) showing glucose metabolism. (From Mazziotta, JC, and Gilman, S: Clinical Brain Imaging: Principles and Applications. Philadelphia: FA Davis, 1992, pp 27 and 298, with permission.)

Box 1–3 | WATCHING THE BRAIN AT WORK

Functional magnetic resonance imaging (**fMRI**) is similar to a PET scan in that it portrays activity within the brain. An fMRI depicts blood flow, and colors to make the gradations of flow distinct are assigned by a computer. An actual fMRI is more of a video than a photograph, and it illustrates physiology and anatomy. In Box Fig. 1–B, each part (A or B) is similar to a



Box Figure 1–B Depiction of a functional MRI, with increased brain activity shown in orange. (**A**) The posterior cerebrum engaged in driving a car. (**B**) The posterior cerebrum, driving and talking on a phone.

Box 1–3 | WATCHING THE BRAIN AT WORK *(Continued)*

"still," or single frame from a movie, and shows what an fMRI would look like in two posterior views of the parietal and occipital lobes of the cerebrum (the pink structure below the occipital lobes is the cerebellum).

Increased brain activity while driving a car (in a simulator) is depicted in part A; this activity is in areas devoted to vision and to analyzing spatial relationships. Part B shows a brain that is driving and talking on a cell phone. You can see that brain activity devoted to driving is diminished. Why might this happen? Because when we talk on a phone we form mental images of the person to whom we are speaking, and we are probably thinking about what we are going to say next. Therefore, those parts of the brain busy with the phone call are not available to look at and analyze the road ahead. Much of driving requires thinking such as "What does what I am seeing mean, and what will I do with that information?" The human brain does best when it focuses on one task; a brain that is distracted by another task is not at all efficient at interpretation or reacting to sudden hazards, and it does neither task well. Evaluations of brain activity such as these can tell us a great deal about how the parts of the brain work together and may also be very useful in the diagnosis or monitoring of certain types of brain damage or disease.

SUMMARY

As you will see, the terminology presented in this chapter is used throughout the text to describe the anatomy of organs and the names of their parts. All organs of the body contribute to homeostasis, the healthy state of the body that is maintained by constant and appropriate responses to internal and external changes. In the chapters that follow, you will find detailed descriptions of the physiology of each organ and organ system, and how the metabolism of each is necessary to homeostasis. We will now return to a consideration of the structural organization of the body and to more extensive descriptions of its levels of organization. The first of these, the chemical level, is the subject of the next chapter.

STUDY OUTLINE

Introduction

1. Anatomy—the study of structure.
2. Physiology—the study of function.
3. Pathophysiology—the study of disorders of functioning.

Levels of Organization

1. Chemical—inorganic and organic chemicals make up all matter, both living and non-living. The body is a container of chemicals.
2. Cells—the smallest living units of the body. The body may be likened to a city of cells.
3. Tissues—groups of cells with similar structure and function.
4. Organs—groups of tissues (a cooperation of tissues) that contribute to specific functions.
5. Organ systems—groups of organs that work together to perform specific functions (see Table 1–1 and Fig. 1–2).
6. Person—all the organ systems functioning properly.
7. The Rest of "Us"—our microbiota, the bacterial population that resides on and inside each human being and contributes to health in many ways, most of which we have yet to discover.

Metabolism and Homeostasis

1. Metabolism is the sum of all of the chemical and physical changes that take place in the body. Metabolic rate is the amount of energy and heat production per unit of time.
2. Homeostasis is a state of good health maintained by the normal metabolism (functioning) of the organ systems.
3. The body constantly responds to internal and external changes yet remains stable; its many aspects of metabolism are kept within normal limits (usually a range of values, not a single value).
4. Negative feedback mechanism—a control system in which a stimulus initiates a response that reverses or reduces the stimulus, thereby stopping the response until the stimulus occurs again and there is a need for the response (see Fig. 1–3).
5. Positive feedback mechanism—a control system that requires an external interruption or brake. Has the potential to become a self-perpetuating and harmful cycle, therefore is rare in the body (see Fig. 1–3).

Terminology and General Plan of the Body

1. Body parts and areas—see Table 1–2 and Fig. 1–4.
2. Terms of location and position—used to describe relationships of position (see Table 1–3 and Figs. 1–4 and 1–5).
3. Body cavities and their membranes (see Fig. 1–5).
    a. Cranial and spinal cavities—within the skull and backbone; lined with membranes called meninges; enclosed by bone to protect the central nervous system.
        — Cranial cavity contains the brain.
        — Spinal (vertebral) cavity contains the spinal cord.
    b. Thoracic, abdominal, and pelvic cavities—within the trunk; the diaphragm separates the thoracic and abdominal cavities; the pelvic cavity is inferior to the abdominal cavity.
        — Thoracic cavity—contains the lungs and heart.
            1) Pleural membranes line the chest wall and cover the lungs.
            2) Pericardial membranes surround the heart.
        — Abdominal cavity—contains many organs including the stomach, liver, and intestines.
            1) The peritoneum lines the abdominal cavity; the mesentery covers the abdominal organs.
        — Pelvic cavity—contains the urinary bladder and reproductive organs.
4. Planes and sections—cutting the body or an organ in a specific way (see Fig. 1–6).
    a. Frontal or coronal—separates front and back parts.
    b. Sagittal—separates right and left parts.
    c. Transverse—separates upper and lower parts.
    d. Cross—a section perpendicular to the long axis.
    e. Longitudinal—a section along the long axis.
5. Areas of the abdomen—permits easier description of locations:
    a. Quadrants—see Fig. 1–7.
    b. Nine areas—see Fig. 1–7.

REVIEW QUESTIONS

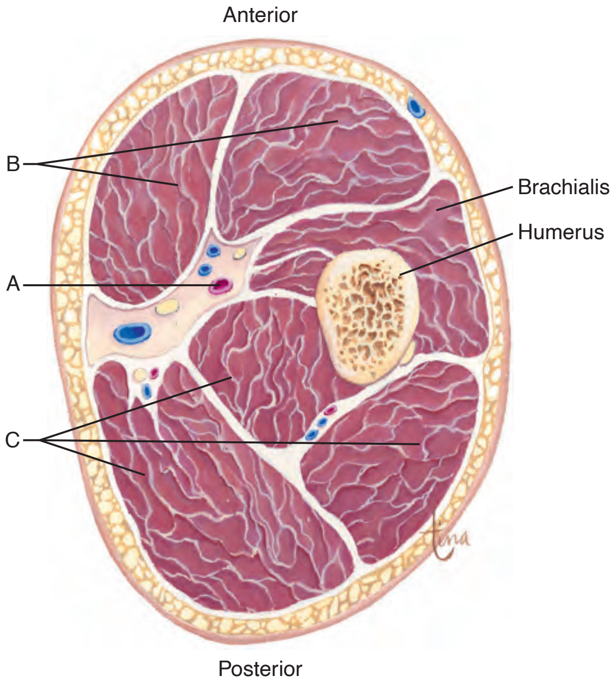
1. Explain how the physiology of a bone is related to its anatomy. Explain how the physiology of the hand is related to its anatomy. (p. 4)
2. Describe anatomic position. Why is this knowledge important? (p. 15)
3. Name the organ system that accomplishes each of the following functions: (p. 8)
    - **a.** Moves the skeleton
    - **b.** Regulates body functions by means of hormones
    - **c.** Covers the body and prevents entry of pathogens
    - **d.** Destroys pathogens that enter the body
    - **e.** Exchanges oxygen and carbon dioxide between the air and blood
4. Name the closed body cavities. Name the cavity lined by the peritoneum, meninges, and parietal pleura. (pp. 15–16)
5. Name the four quadrants of the abdomen. Name at least one organ in each quadrant. (pp. 18–19)
6. Name the section through the body that would result in each of the following: equal right and left halves, anterior and posterior parts, superior and inferior parts. (pp. 17–18)
7. Review Table 1–2 and try to find each external area on your own body. (pp. 13–14)
8. Define *cell*. When similar cells work together, what name are they given? (p. 4)
9. Define *organ*. When a group of organs works together, what name is it given? (p. 6)
10. Define *metabolism, metabolic rate,* and *homeostasis.* (p. 11)
    - **a.** Give an example of an external change and explain how the body responds to maintain homeostasis.
    - **b.** Give an example of an internal change and explain how the body responds to maintain homeostasis.
    - **c.** Briefly explain how a negative feedback mechanism works and how a positive feedback mechanism differs.

FOR FURTHER THOUGHT

1. The human foot is similar to the human hand, but it does have anatomic differences. Describe two of these differences, and explain how they are related to the physiology of the hand and the foot.
2. If a person has appendicitis (inflammation of the appendix caused by bacteria), pain is felt in which abdominal quadrant? (If you're not sure, take a look at Fig. 16–1 in Chapter 16.) Surgery is usually necessary to remove an inflamed appendix before it ruptures and causes peritonitis. Using your knowledge of the location of the peritoneum, explain why peritonitis is a very serious condition.
3. Keep in mind your answer to Question 3, and explain why bacterial meningitis can be a very serious infection.
4. Use a mental picture to cut the following sections. Then describe in simple words what each section looks like, and give each a proper anatomic name.

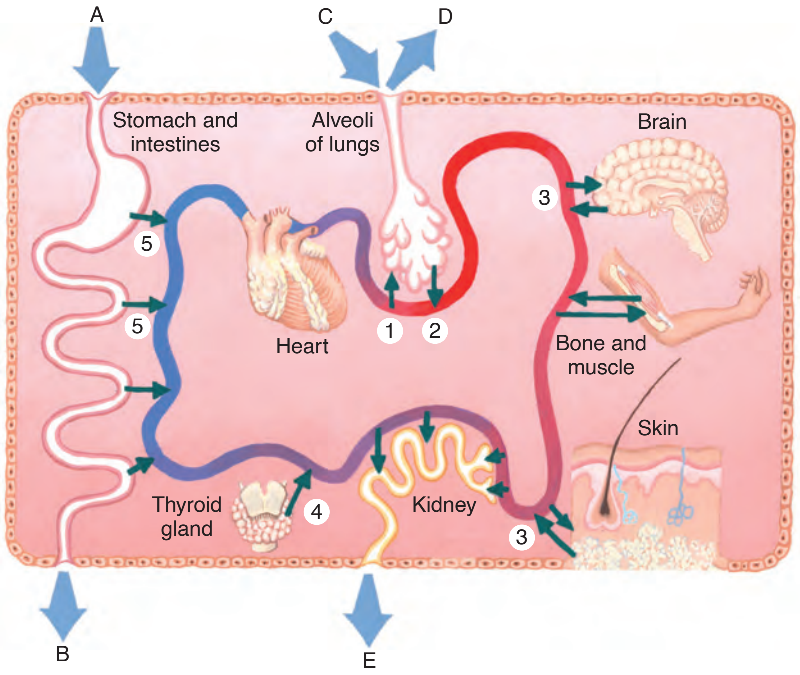
   First: a tree trunk cut top to bottom, then cut side to side.

   Second: a grapefruit cut top to bottom (straight down from where the stem was attached), then sliced through its equator.
5. Look at Question Figure 1–A. This is a transverse section through the middle of the right upper arm; the front of the arm is at the top of the picture, away from you, oriented the same way you would see your own right arm. Can you name the labeled structures? Need help? Go back to the section *Body Parts and Areas* or look ahead to Fig. 7–11 in Chapter 7.



QUESTION FIGURE 1–A: A midtransverse section of right upper arm.

6. Question Figure 1–B is a schematic representation of the interdependency of several of the body's organ systems depicted in a rectangular organism. The lettered arrows represent interactions of the body with the environment. The number arrows represent internal interactions. Label each arrow with what is moving.



QUESTION FIGURE 1–B: Relationships of organ systems.

CHAPTER

2

Some Basic Chemistry

STUDENT OBJECTIVES

- Define the terms *element*, *atom*, *proton*, *neutron*, and *electron.*
- Describe the formation and purpose of ionic bonds, covalent bonds, disulfide bonds, and hydrogen bonds.
- Describe what happens in synthesis and decomposition reactions.
- Explain the importance of water to the functioning of the human body.
- Name and describe the water compartments.
- Explain the roles of oxygen and carbon dioxide in cell respiration.
- State what trace elements are and name some, with their functions.
- Explain the pH scale. State the normal pH ranges of body fluids.
- Explain how a buffer system limits great changes in pH.
- Describe the functions of monosaccharides, disaccharides, oligosaccharides, and polysaccharides.
- Describe the functions of true fats, phospholipids, and steroids.
- Describe the functions of proteins, and explain how enzymes function as catalysts.
- Describe the functions of DNA, RNA, and ATP.

NEW TERMINOLOGY

Acid *(**ASS**-sid)*
Amino acid *(ah-**MEE**-noh **ASS**-sid)*
Atom *(**A**-tum)*
Base *(BAYSE)*
Buffer system *(**BUFF**-er **SIS**-tem)*
Carbohydrates *(KAR-boh-**HIGH**-drayts)*
Catalyst *(**KAT**-ah-list)*
Cell respiration *(SELL RES-pi-**RAY**-shun)*
Covalent bond *(ko-**VAY**-lent)*
Dissociation/ionization *(dih-SOH-see-**AY**-shun/EYE-uh-nih-**ZAY**-shun)*
Element *(**EL**-uh-ment)*
Enzyme *(**EN**-zime)*
Extracellular fluid *(EKS-trah-**SELL**-yoo-ler)*
Intracellular fluid *(IN-trah-**SELL**-yoo-ler)*
Ion *(**EYE**-on)*
Ionic bond *(eye-**ON**-ik)*
Lipids *(**LIP**-ids)*
Matter *(**MAT**-ter)*
Molecule *(**MAHL**-e-kuhl)*
Nucleic acids *(new-**KLEE**-ik **ASS**-sids)*
pH and pH scale *(pee-H SKALE)*
Protein *(**PROH**-teen)*
Salt *(SAWLT)*
Solvent/solution *(**SAHL**-vent/suh-**LOO**-shun)*
Steroid *(**STEER**-oyd)*
Theory *(**THEER**-ree)*
Trace elements *(TRAYSE **EL**-uh-ments)*

RELATED CLINICAL TERMINOLOGY

Acidosis *(ASS-i-**DOH**-sis)*
Atherosclerosis *(ATH-er-oh-skle-**ROH**-sis)*
Hypoxia *(high-**POK**-see-ah)*
Saturated *(**SAT**-uhr-ay-ted)*
Unsaturated *(un-**SAT**-uhr-ay-ted)*

*Terms that appear in **bold type** in the chapter text are defined in the glossary, which begins on page 603.*

CHAPTER OUTLINE

Elements
Atoms
Chemical Bonds
Ionic Bonds
Covalent Bonds
Disulfide Bonds and Hydrogen Bonds
Chemical Reactions
Inorganic Compounds of Importance
Water
Water Compartments
Oxygen
Carbon Dioxide
Cell Respiration
Trace Elements
Acids, Bases, and pH
Buffer Systems
Organic Compounds of Importance
Carbohydrates
Lipids
Proteins
Enzymes
Nucleic Acids
DNA and RNA
ATP

BOX 2–1
Blood Gases

BOX 2–2
Nitric Oxide

BOX 2–3
Vegetables: Tears and Gas

BOX 2–4
Lipids in the Blood

BOX 2–5
A Protein Mystery: Prions

When you hear or see the word "chemistry," you may think of test tubes and beakers in a laboratory experiment. For our study of the human body, however, let us think of our laboratory as a kitchen with pots and pans and good food simmering on the stove or baking in the oven. The scents of that food are carried in the air, which is a mixture of gaseous chemicals that we inhale and exhale. The pots and pans, as well as the paper of a cookbook (once the wood of a tree), are solid chemicals. Water is a liquid chemical, and all of our foods are chemicals. Recall from Chapter 1 that the simplest level of organization is the chemical level. Our bodies are complex arrangements of thousands of chemicals. Where do we obtain new chemicals to make new body parts or supply energy? That's right: from food. Good cooking is a science and as an art. And eating? It's all chemistry.

This chapter covers some very basic aspects of chemistry as they are related to living organisms and most especially as they are related to our understanding of the human body. So try to think of chemistry not as a complicated science, but as the air, water, and food we need, and every substance that is part of us. Before we get to food groups, however, we must begin with the fundamentals of chemical structure: the atoms of elements and the bonds that hold them together.

ELEMENTS

All **matter**, both living and not living, is made of elements, the simplest chemicals. An **element** is a substance made of only one type of atom (therefore, an atom is the smallest part of an element). There are 92 naturally occurring elements in the world around us. Examples are hydrogen (H), iron (Fe), oxygen (O), calcium (Ca), nitrogen (N), and carbon (C). In nature, an element does not usually exist by itself but rather combines with the atoms of other elements to form compounds. Examples of some compounds important to our study of the human body are water (H_2O), in which two atoms of hydrogen combine with one atom of oxygen; carbon dioxide (CO_2), in which an atom of carbon combines with two atoms of oxygen; and glucose ($C_6H_{12}O_6$), in which six carbon atoms and six oxygen atoms combine with 12 hydrogen atoms.

The elements carbon, hydrogen, oxygen, nitrogen, phosphorus, and sulfur are found in all living things. If calcium is included, these seven elements make up approximately 99% of the human body (weight).

More than 20 different elements are found, in varying amounts, in the human body. Some of these are listed in Table 2–1. As you can see, each element has a standard chemical symbol. This is simply the first (and sometimes the second) letter of the element's English or Latin name. You should know the symbols of the elements in this table because they are used in textbooks, articles, hospital lab reports, and so on. Notice that if a two-letter symbol is used for an element, the second letter is always lowercase, not a capital. For example, the symbol for calcium is Ca, not CA. CA is an abbreviation often used for cancer.

Table 2–1 | **ELEMENTS IN THE HUMAN BODY**

ELEMENTS	SYMBOL	ATOMIC NUMBER*	PERCENT OF THE BODY BY WEIGHT
Hydrogen	H	1	9.5
Carbon	C	6	18.5
Nitrogen	N	7	3.3
Oxygen	O	8	65.0
Fluorine	F	9	Trace
Sodium	Na	11	0.2
Magnesium	Mg	12	0.1
Phosphorus	P	15	1.0
Sulfur	S	16	0.3
Chlorine	Cl	17	0.2
Potassium	K	19	0.4
Calcium	Ca	20	1.5
Manganese	Mn	25	Trace
Iron	Fe	26	Trace
Cobalt	Co	27	Trace
Copper	Cu	29	Trace
Zinc	Zn	30	Trace
Iodine	I	53	Trace

*Atomic number is the number of protons in the nucleus of the atom. It is also the number of electrons that orbit the nucleus.

ATOMS

Atoms are the smallest parts of an element that have the characteristics of that element. An atom consists of three major subunits or particles: protons, neutrons, and electrons (Fig. 2–1). A **proton** has a positive electrical charge and is found in the nucleus (or center) of the atom. A **neutron** is electrically neutral (has no charge) and is also found in the nucleus. An **electron** has a negative electrical charge and is found outside the nucleus orbiting in what may be called an electron cloud or shell around the nucleus.

The number of protons in an atom gives it its **atomic number**. Protons and neutrons have mass and weight; they give an atom its **atomic weight**. In an atom, the number of protons (+) equals the number of electrons (–); therefore, an atom is electrically neutral. The electrons, however, are important in that they may enable an atom to connect or **bond** to other atoms to form **molecules**. A molecule is a combination of atoms (usually of more than one element) that are so tightly bound together that the molecule behaves as a single unit.

Each atom is capable of bonding in only very specific ways. This capability depends on the number and the arrangement of the electrons of the atom. Electrons orbit the nucleus of an atom in shells or **energy levels**. The first, or innermost, energy level can contain a maximum of two electrons and is then considered stable. The second energy level is stable when it contains its maximum of eight electrons. The remaining energy levels, more distant from the nucleus, are also most stable when they contain eight electrons, or a multiple of eight.

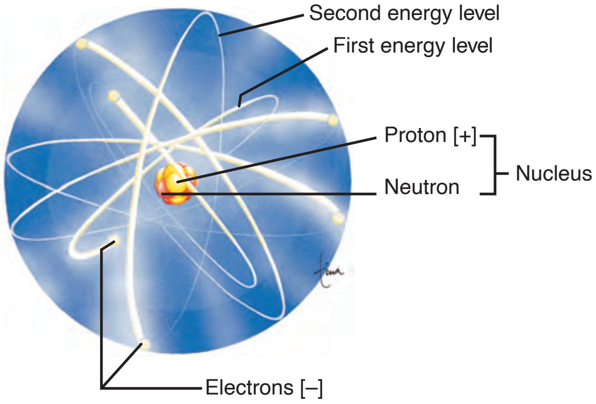


Figure 2–1 An atom of carbon. The nucleus contains six protons and six neutrons (not all are visible here). Six electrons orbit the nucleus, two in the first energy level and four in the second energy level.

QUESTION: What is the electrical charge of this atom as a whole?

A few atoms (elements) are naturally stable, or uninterested in reacting, because their outermost energy level already contains the maximum number of electrons. The gases helium and neon are examples of these stable atoms, which do not usually react with other atoms. Most atoms are not stable, however, and tend to gain, lose, or share electrons in order to fill their outermost shell. By doing so, an atom is capable of forming one or more chemical bonds with other atoms. In this way, the atom becomes stable because its outermost shell of electrons has been filled. It is these reactive atoms that are of highest interest in our study of anatomy and physiology.

CHEMICAL BONDS

A chemical bond is not a structure, but rather a force or attraction between positive and negative electrical charges. A chemical bond keeps two or more atoms closely associated with each other to form a molecule. By way of comparison, think of gravity. We know that gravity is not a “thing,” but rather the force that keeps our feet on the floor and allows us to pour coffee with consistent success. Molecules formed by chemical bonding often have physical characteristics different from those of the atoms of the original elements. For example, the elements hydrogen and oxygen are gases, but atoms of each may chemically bond to form molecules of water, which is a liquid.

The type of chemical bonding depends on the tendencies of the electrons of atoms involved, as you will see. Four kinds of bonds are very important to the chemistry of the body: ionic bonds, covalent bonds, disulfide bonds, and hydrogen bonds.

IONIC BONDS

An **ionic bond** involves the loss of one or more electrons by one atom and the gain of the electron(s) by another atom or atoms. Refer to Fig. 2–2 as you read the following.

An atom of sodium (Na) has one electron in its outermost shell, and, in order to become stable, it tends to lose that electron. When it does so, the sodium atom has one more proton than it has electrons. Therefore, it now has an electrical charge (or **valence**) of +1 and is called a sodium **ion** (Na^+). An atom of chlorine has seven electrons in its outermost shell, and in order to become stable it tends to gain one electron. When it does so, the chlorine atom has one more electron than it has protons and now has a charge (valence) of –1. It is called a chloride ion (Cl^-).

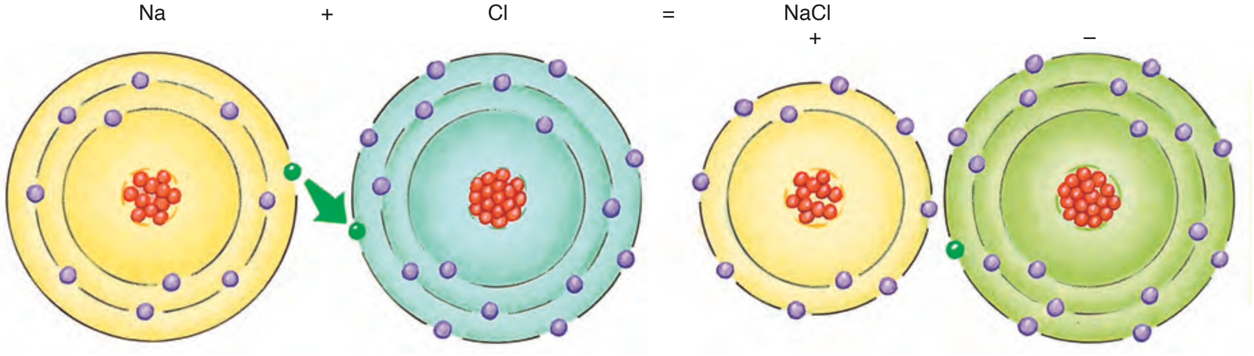


Figure 2–2 Formation of an ionic bond. An atom of sodium loses an electron to an atom of chlorine. The two ions formed have unlike charges, are attracted to one another, and form a molecule of sodium chloride.

QUESTION: Why is the charge of a sodium ion +1?

When an atom of sodium loses an electron to an atom of chlorine, their ions have unlike charges (positive and negative) and are thus attracted to one another. The result is the formation of a molecule of sodium chloride: NaCl, or common table salt. The bond that holds these ions together is called an ionic bond.

Another example is the bonding of chlorine to calcium. An atom of calcium has two electrons in its outermost shell and tends to lose those electrons in order to become stable (a calcium ion, Ca^{+2}). If two atoms of chlorine each gain one of those electrons, they become chloride ions. The positive and negative ions are then attracted to one another, forming a molecule of calcium chloride, $CaCl_2$, which is also a salt. A **salt** is a molecule made of ions other than hydrogen (H^+) ions or hydroxyl (OH^-) ions.

Ions with positive charges are called **cations**. These include Na^+, Ca^{+2}, K^+, Fe^{+2}, and Mg^{+2}. Ions with negative charges are called **anions**, which include Cl^-, SO_4^{-2} (sulfate), and HCO_3^- (bicarbonate). The types of compounds formed by ionic bonding are inorganic salts, acids, and bases. (Acids and bases are discussed later in this chapter.)

In the solid state, ionic bonds are relatively strong. Our bones, for example, contain the salt calcium carbonate ($CaCO_3$), which helps give bone its strength. In an **aqueous** (water) **solution**, however, many ionic bonds are weakened. The bonds may become so weak that the bound ions of a molecule separate, creating a solution of free positive and negative ions. For example, if sodium chloride is put in water, it dissolves and then **ionizes**. The water now contains Na^+ ions and Cl^- ions. Ionization, also called **dissociation**, is important to living organisms because the ions produced are free to take part in other chemical reactions within the body. Cells in the stomach lining must have Cl^- ions to produce hydrochloric acid (HCl). The chloride in NaCl would not be free to take part in another reaction because it is tightly bound to the sodium atom. However, the Cl^- ions available from ionized NaCl in the cellular water can be used for the **synthesis**, or chemical manufacture, of HCl in the stomach.

COVALENT BONDS

Covalent bonds involve the sharing of electrons between atoms. As shown in Fig. 2–3, an atom of oxygen needs two electrons to become stable. It may share two of its electrons with another atom of oxygen, also sharing two electrons. Together they form a molecule of oxygen gas (O_2), which is the form in which oxygen exists in the atmosphere.

An atom of oxygen may also share two of its electrons with two atoms of hydrogen, each sharing its single electron (see Fig. 2–3). Together they form a molecule of water (H_2O). When writing structural formulas for chemical molecules, a pair of shared electrons is indicated by a single line, as shown in Fig. 2–3, the formula for water; this is a single covalent bond. A double covalent bond is indicated by two lines, as in the formula for oxygen; this represents two pairs of shared electrons.

The element carbon always forms covalent bonds; an atom of carbon has four electrons to share with other atoms. If these four electrons are shared with four atoms

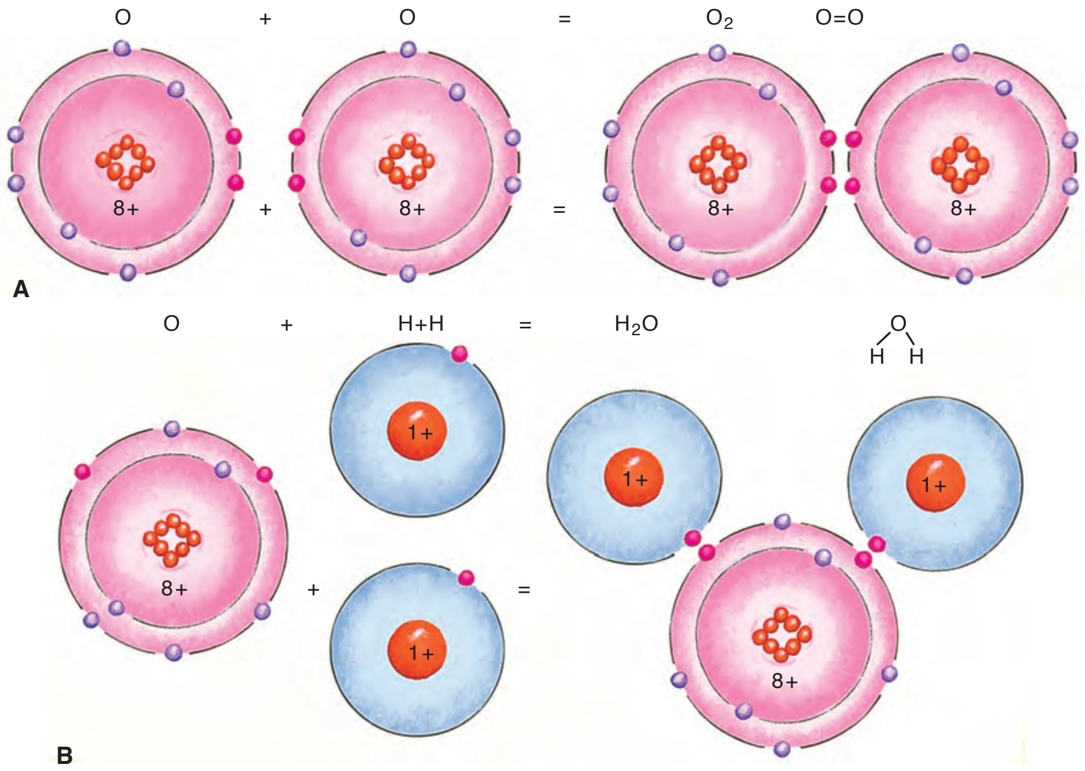


Figure 2–3 Formation of covalent bonds. (**A**) Two atoms of oxygen share two electrons each, forming a molecule of oxygen gas. (**B**) An atom of oxygen shares one electron with each of two hydrogen atoms, each sharing its electron. A molecule of water is formed.

QUESTION: Which of the bonds shown here is a double covalent bond?

of hydrogen, each sharing its one electron, a molecule of methane gas (CH_4) is formed. Carbon may form covalent bonds with other carbons, hydrogen, oxygen, nitrogen, or other elements. Organic compounds such as proteins and carbohydrates are complex and precise arrangements of these atoms, covalently bonded to one another. Covalent bonds are relatively strong and are not weakened in an aqueous solution. This is important because the proteins produced by the body, in muscle and skin, for example, must remain intact in order to function properly in the water of our cells and blood. The functions of organic compounds will be considered later in this chapter.

DISULFIDE BONDS AND HYDROGEN BONDS

Two other types of bonds that are important to the chemistry of the body are disulfide bonds and hydrogen bonds. Disulfide bonds are found in some proteins. Hydrogen bonds are part of many different molecules.

A **disulfide bond** (also called a disulfide bridge) is a covalent bond formed between two atoms of sulfur, usually within the same large protein molecule. The hormone insulin, for example, is a protein that must have a very specific three-dimensional shape in order to function properly to regulate the blood glucose level. Each molecule of insulin has two disulfide bonds that help maintain its proper shape and function (see Box Fig. 10–A in Chapter 10). Other proteins with shapes that depend upon disulfide bonds are antibodies of the immune system (see Fig. 14–8 in Chapter 14) and keratin of the skin and hair.

A strand of hair maintains its shape (a genetic characteristic) because of disulfide bonds. When naturally curly hair is straightened, the disulfide bonds in the keratin molecules are broken. When naturally straight hair is "permed" or curled, the disulfide bonds in the keratin are first broken, then re-formed in the curled hair. Neither process affects the living part of the hair, the hair root, so the hair will grow out in its original shape. We would not want such a process affecting our insulin or antibody molecules, for that would destroy their functioning.

A **hydrogen bond** does not involve the sharing or exchange of electrons, but rather results from a property of hydrogen atoms. When a hydrogen atom shares its one electron in a covalent bond with another atom, its proton has a slight positive charge and may then be attracted to a nearby oxygen or nitrogen atom, which has a slight negative charge.

Although they are weak bonds, hydrogen bonds are important in several ways. Large organic molecules such as proteins and the DNA in our chromosomes have very specific functions that depend upon their three-dimensional shapes (see Fig. 2–10). The shapes of these molecules, so crucial to their proper functioning, are often maintained by hydrogen bonds.

Hydrogen bonds also make water cohesive. **Cohesion** is the tendency of similar molecules to “stick to” one another. In a glass of water, for example, each water molecule is attracted to nearby water molecules. One water molecule forms up to four hydrogen bonds, one with each of four other water molecules. Each of those four molecules can form four hydrogen bonds, and so on, making all of the water cohesive. Water can also be adhesive with other molecules. **Adhesion** is the tendency of unlike molecules to be attracted to one another. Both the cohesion and adhesion of water molecules is what keeps the grains of a sand castle together. The cohesiveness of water itself can be seen if water is dropped onto clean glass; the surface tension created by the hydrogen bonds makes the water form three-dimensional beads. Within the body, the cohesiveness of water helps keep blood a continuous stream as it flows within the blood vessels and also keeps tissue fluid continuous around cells. These hydrogen bonds are also responsible for the other important characteristics of water, which are discussed in a later section.

CHEMICAL REACTIONS

A chemical reaction is a change brought about by the formation or breaking of chemical bonds. Two general types of reactions are synthesis reactions and decomposition reactions.

In a **synthesis reaction**, bonds are formed to join two or more atoms or molecules to make a new compound. The production of the protein hemoglobin in potential red blood cells is an example of a synthesis reaction. Proteins are synthesized by the bonding of many amino acids, their smaller subunits. Synthesis reactions require energy for the formation of bonds.

In a **decomposition reaction**, bonds are broken, and a large molecule is changed to two or more smaller ones. One example is the digestion of large molecules of starch into many smaller glucose molecules. Some decomposition reactions release energy; this is described in a later section on cell respiration.

Within cells, synthesis is often coupled with decomposition. When membranes or other cell parts break down, they must be replaced. The old or damaged structures may be recycled for their smaller parts or subunits. These parts can be minerals (such as iron) or organic molecules (such as amino acids) and can be used in subsequent synthesis reactions. When older hemoglobin breaks down, for example, its iron can be used over and over to synthesize new hemoglobin for red blood cells (this will be covered in Chapter 11).

In this and future chapters, keep in mind that the term *reaction* refers to the making or breaking of chemical bonds and thus to changes in the physical and chemical characteristics of the molecules involved.

INORGANIC COMPOUNDS OF IMPORTANCE

Inorganic compounds are usually simple molecules that often consist of only one or two different elements. Despite their simplicity, however, some inorganic compounds are essential to normal structure and functioning of the body.

WATER

Water makes up 55% to 70% of the human body and is essential to life for several reasons:

1. *Water is a* ***solvent;*** that is, many substances (called solutes) can dissolve in water. Nutrients such as glucose are dissolved in blood plasma (which is largely water) to be transported to cells throughout the body. The excretion of waste products is possible because the products are dissolved in the water of urine produced by the kidneys. The senses that enable us to enjoy our food, taste and smell, both depend upon the solvent ability of water. Food molecules dissolved in saliva stimulate receptors in taste buds on the tongue. Vaporized food molecules

(especially from hot foods) are sniffed into the upper nasal cavities, where they dissolve in the thin film of water and stimulate olfactory receptors. Hot foods often seem more tasty than cold foods because the sense of smell contributes more to our perception of them.

2. *Water is a lubricant*, which prevents friction where surfaces meet and move. In the digestive tract, swallowing depends on the presence of saliva, and mucus is a slippery fluid that permits the smooth passage of food through the intestines. Synovial fluid within joint cavities prevents friction as bones move.
3. *Water changes temperature slowly.* Water has a high heat capacity, which means that it will absorb a great deal of heat before its temperature rises significantly, or it must lose a great deal of heat before its temperature drops significantly. This is one of the factors that helps the body maintain a constant temperature. Water also has a high heat of vaporization, the heat needed to change water from a liquid to a gas. This is important for the process of sweating. Excess body heat evaporates sweat on skin surfaces, rather than overheating the body's cells, and because of water's high heat of vaporization, a great deal of heat can be given off with the loss of a relatively small amount of water.

WATER COMPARTMENTS

All water within the body is continually moving, but water is given different names when it is in specific body locations, which are called compartments (Fig. 2–4):

Intracellular fluid (ICF —the water within cells; about 65% of the total body water

Extracellular fluid (ECF) —all the rest of the water in the body; about 35% of the total. More specific compartments of extracellular fluid include the following:

Plasma—water found in blood vessels

Lymph—water found in lymphatic vessels

Tissue fluid or interstitial flu —water found in the small spaces between cells

Specialized fluid —synovial fluid in joints, cerebrospinal fluid around the brain and spinal cord aqueous humor in the eye, and others

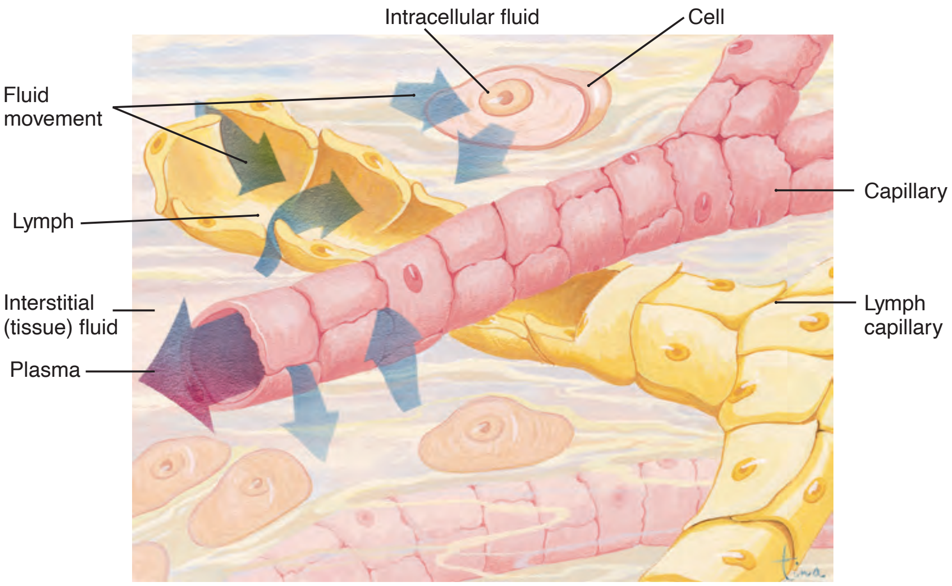


Figure 2–4 Water compartments, showing the names that water is given in its different locations and the ways in which water moves between compartments.

QUESTION: Which of the fluids shown are extracellular fluids?

The movement of water between compartments in the body and the functions of the specialized fluids will be discussed in later chapters.

OXYGEN

Oxygen in the form of a gas (O_2) is approximately 21% of the atmosphere, which we inhale. We all know that without oxygen we wouldn't survive very long, but exactly what does oxygen do? Oxygen is important to us because it is essential for a process called cell respiration, in which cells break down simple nutrients such as glucose in order to release energy. The reason we breathe is to obtain oxygen for cell respiration and to exhale the carbon dioxide produced in cell respiration (this will be discussed in the next section). Biologically useful energy that is released by the reactions of cell respiration is trapped in a molecule called ATP (adenosine triphosphate). ATP can then be used for cellular processes that require energy.

CARBON DIOXIDE

Carbon dioxide (CO_2) is produced by cells as a waste product of cell respiration. You may ask why a waste product is considered important. Keep in mind that "important" does not always mean "beneficial"; instead, it can mean "significant." If the amount of carbon dioxide in the body fluids increases, it causes these fluids to become too acidic. Therefore, carbon dioxide must be exhaled as rapidly as it is formed to keep the amount in the body within normal limits. Normally this is just what happens, but severe pulmonary diseases such as pneumonia or emphysema decrease gas exchange in the lungs, resulting in the accumulation of carbon dioxide in the blood. When this happens, a person is said to be in a state of **acidosis**, which may seriously disrupt body functioning (see the sections on pH and enzymes later in this chapter; see also Box 2–1: Blood Gases).

CELL RESPIRATION

Cell respiration is the name for energy production within cells and involves both respiratory gases, oxygen and carbon dioxide. Many chemical reactions are involved, some of which take place in cell organelles called **mitochondria**. In its simplest form, cell respiration may be summarized by the following equation:

$$\text{Glucose } (C_6H_{12}O_6) + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{ATP} + \text{heat}$$

Box 2–1 | BLOOD GASES

A patient is admitted to the emergency department with a possible heart attack, and the doctor in charge orders "blood gases." Another patient hospitalized with pneumonia has "blood gases" monitored at frequent intervals. What are blood gases, and what does measurement of them tell us? The blood gases are oxygen and carbon dioxide, and their levels in arterial blood provide information about the functioning of the respiratory and circulatory systems. Arterial blood normally has a high concentration of oxygen and a low concentration of carbon dioxide. These levels are maintained by gas exchange in the lungs and by the proper circulation of blood.

A pulmonary disease such as pneumonia interferes with efficient gas exchange in the lungs. As a result, blood oxygen concentration may decrease, and blood carbon dioxide concentration may increase. Either of these changes in blood gases may become life threatening for the patient, so monitoring of blood gases is important. If blood oxygen falls below the normal range, oxygen will be administered; if blood carbon dioxide rises above the normal range, blood pH will be corrected to prevent serious acidosis.

Damage to the heart may also bring about a change in blood gases, especially oxygen. Oxygen is picked up by red blood cells as they circulate through lung capillaries; as red blood cells circulate through the body, they release oxygen to tissues. What keeps the blood circulating or moving? The pumping of the heart.

A mild heart attack, when heart failure is unlikely, is often characterized by a blood oxygen level that is low but still within normal limits. A more severe heart attack that seriously impairs the pumping of the heart will decrease the blood oxygen level to less than normal; this is called **hypoxemia**. A consequence is **hypoxia**, which means that too little oxygen is reaching tissues. When this is determined by measurement of blood gases, appropriate oxygen therapy can be started to correct the hypoxia and prevent tissue death.

This reaction shows us that glucose and oxygen combine to yield carbon dioxide, water, ATP, and heat. Food, represented here by glucose, in the presence of oxygen is broken down into the simpler molecules carbon dioxide and water. The potential energy in the glucose molecule is released in two forms: ATP and heat. Each of the four products of this process has a purpose or significance in the body. The carbon dioxide is a waste product that moves from the cells into the blood, which carries it to the lungs where it is eventually exhaled. The water formed is useful and becomes part of the intracellular fluid. The heat produced contributes to normal body temperature. ATP is used for cell processes such as mitosis, protein synthesis, and muscle contraction, all of which require energy and will be discussed a bit further on in the text.

We will also return to cell respiration in later chapters and to mitochondria in Chapter 3. For now, the brief description just given will suffice to show that eating and breathing are interrelated; both are essential for energy production.

TRACE ELEMENTS

Trace elements are those that are needed by the body in very small amounts. When they are present in food or nutritional supplements, we often call them minerals. Examples are iron (found in meat and legumes), cobalt (found only in animal foods such as liver and fish), magnesium (found in green vegetables because it is part of chlorophyll), and iodine (found in seafood and iodized salt). Although trace elements may not be as abundant in the body as carbon, hydrogen, and oxygen, they are nonetheless essential. Table 2–2 lists some of these trace elements and their functions. Calcium and phosphorus (found in milk, cheese, meat, and fish) are included in this table, though they are needed in somewhat larger amounts than are the others. (See also Box 2–2: Nitric Oxide.)

ACIDS, BASES, AND PH

An **acid** may be defined as a substance that increases the concentration of hydrogen ions (H^+) in a water solution. A **base** is a substance that decreases the concentration of H^+ ions, which, in the case of water, has the same effect as increasing the concentration of hydroxyl ions (OH^-).

The acidity or alkalinity (basicity) of a solution is measured on a scale of values called **pH** (parts hydrogen). The values on the **pH scale** range from 0 to 14, with 0 indicating the most acidic level and 14 the most alkaline. A solution with a pH of 7 is neutral because it

Table 2–2 | **TRACE ELEMENTS**

ELEMENT	FUNCTION
Calcium	■ Provides strength in bones and teeth ■ Necessary for blood clotting ■ Necessary for muscle contraction
Phosphorus	■ Provides strength in bones and teeth ■ Part of DNA, RNA, and ATP ■ Part of cell membranes in phospholipids
Iron	■ Part of hemoglobin in red blood cells; transports oxygen ■ Part of myoglobin in muscles; stores oxygen ■ Part of mitochondria in cells; necessary for cell respiration
Copper	■ Part of mitochondria in cells; necessary for cell respiration ■ Necessary for hemoglobin synthesis
Magnesium	■ Necessary for energy production and bone formation
Sodium and potassium	■ Necessary for muscle contraction and nerve impulse transmission ■ Necessary for proper movement of water (osmosis) among its compartments
Sulfur	■ Part of some proteins such as insulin, keratin, and antibodies
Cobalt	■ Part of vitamin B_{12}
Iodine	■ Part of thyroid hormones (thyroxine); essential for normal mental and physical development

Box 2–2 | NITRIC OXIDE

Nitric oxide is a gas with the molecular formula NO (N=O, a double covalent bond). You have probably heard of it as a component of air pollution and cigarette smoke, but it is synthesized by several human tissues, and this deceptively simple molecule has important functions.

Nitric oxide is produced by the endothelium (lining) of blood vessels and promotes vasodilation of arterioles, permitting greater blood flow and oxygen delivery to tissues. It is involved in nerve impulse transmission in the brain, and it may contribute to memory storage. Some immune system cells produce nitric oxide as a cytotoxic (cell-poisoning) agent to help destroy foreign cells such as bacteria.

Nitric oxide is also being used therapeutically. It has been found useful in the treatment of pulmonary hypertension to relax abnormally constricted arteries in the lungs to permit normal gas exchange. Other studies show that nitric oxide helps some premature babies breathe more easily and efficiently. With short-term treatment, serious side effects have not yet been found.

contains the same number of H^+ ions and OH^- ions. Pure water has a pH of 7. A solution with a higher concentration of H^+ ions than OH^- ions is an acidic solution with a pH below 7. An alkaline solution, therefore, has a higher concentration of OH^- ions than H^+ ions and has a pH above 7.

The pH scale, with the relative concentrations of H^+ ions and OH^- ions, is shown in Fig. 2–5. A change of one pH unit is a 10-fold change in H^+ ion concentration. This means that a solution with a pH of 4 has 10 times as many H^+ ions as a solution with a pH of 5 and 100 times as many H^+ ions as a solution with a pH of 6. Figure 2–5 also shows the pH of some body fluids and other familiar solutions. Notice that gastric juice has a pH of 1 and coffee has a pH of 5. This means that gastric juice has 10,000 times as many H^+ ions as coffee has. Although coffee is acidic, it is a weak acid and does not have the corrosive effect of gastric juice, a strong acid.

The cells and internal fluids of the human body have a pH close to neutral. The pH of intracellular fluid is around 6.8 to 7.0, and the normal pH range of blood is 7.35 to 7.45. Fluids such as gastric juice and urine are technically external fluids because they are in body tracts that open to the environment. The pH of these fluids may be more strongly acidic or alkaline without harm to the body.

The pH of blood, however, must be maintained within its very narrow, slightly alkaline range. A decrease of only one pH unit, which is 10 times as many H^+ ions, would disrupt the chemical reactions of the blood and cause the death of the individual. Normal metabolism tends to make body fluids more acidic, and this tendency to acidosis must be continually corrected. Normal pH of internal fluids is maintained by the kidneys, respiratory system, and buffer systems. Although acid–base balance will be a major topic of Chapter 19, we will briefly mention buffer systems here.

Buffer Systems

A **buffer system** is a chemical or pair of chemicals that minimizes changes in pH by reacting with strong acids or strong bases to transform them into substances that will not drastically change pH. Expressed in another way, a buffer may bond to H^+ ions when a body fluid is becoming too acidic, or release H^+ ions when a fluid is becoming too alkaline.

We will use the bicarbonate buffer system as a specific example. This system consists of carbonic acid (H_2CO_3), a weak acid, and sodium bicarbonate ($NaHCO_3$), a weak base. This pair of chemicals is present in all body fluids but is especially important to buffer blood and tissue fluid.

Carbonic acid ionizes as follows (but remember, because it is a weak acid it does not contribute many H^+ ions to a solution):

$$H_2CO_3 \rightarrow H^+ + HCO_3^-$$

Sodium bicarbonate ionizes as follows:

$$NaHCO_3 \rightarrow Na^+ + HCO_3^-$$

If a strong acid, such as HCl, is added to extracellular fluid, the following reaction will occur:

$$HCl + NaHCO_3 \rightarrow NaCl + H_2CO_3$$

What has happened here? Hydrochloric acid, a strong acid that would greatly lower pH, has reacted with sodium

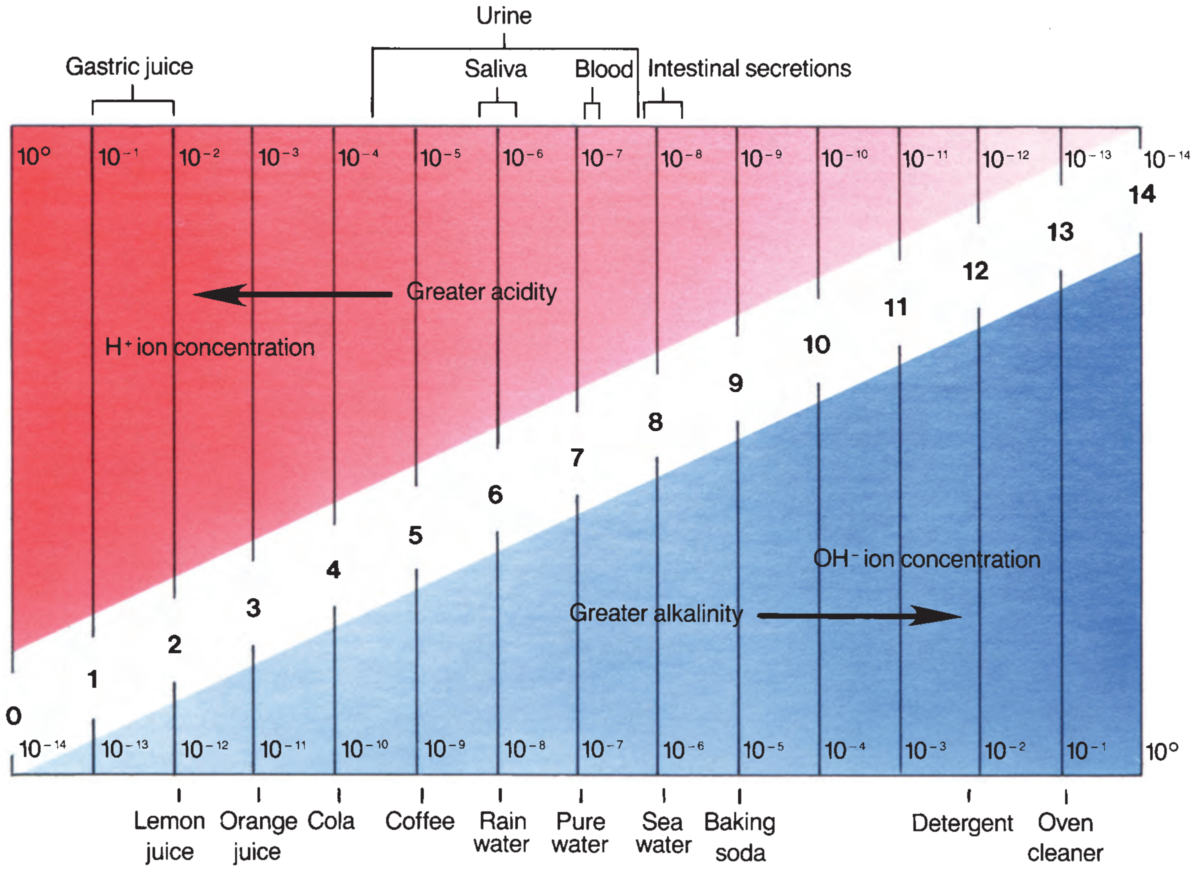


Figure 2–5 The pH scale. The pH values of several body fluids are indicated above the scale. The pH values of some familiar solutions are indicated below the scale.

QUESTION: Describe the pH range of blood compared with the pH range of urine.

bicarbonate. The products of this reaction are NaCl, a salt that has no effect on pH, and H_2CO_3, a weak acid that lowers pH only slightly. This prevents a drastic change in the pH of the extracellular fluid.

If a strong base, such as sodium hydroxide, is added to the extracellular fluid, this reaction will occur:

$$NaOH + H_2CO_3 \rightarrow H_2O + NaHCO_3$$

Sodium hydroxide, a strong base that would greatly raise pH, has reacted with carbonic acid. The products of this reaction are water, which has no effect on pH, and sodium bicarbonate, a weak base that raises pH only slightly. Again, this prevents a drastic change in the pH of the extracellular fluid.

In the body, such reactions take place in less than a second whenever acids or bases are formed that would greatly change pH. Because of the body's tendency to become more acidic, the need to correct acidosis is more frequent. With respect to the bicarbonate buffer system, this means that more $NaHCO_3$ than H_2CO_3 is needed. For this reason, the usual ratio of these buffers is 20:1 ($NaHCO_3$:H_2CO_3).

ORGANIC COMPOUNDS OF IMPORTANCE

Organic compounds all contain covalently bonded carbon and hydrogen atoms and perhaps other elements as well. In the human body there are four major groups of organic compounds: carbohydrates, lipids, proteins, and nucleic acids.

CARBOHYDRATES

A primary function of **carbohydrates** is to serve as sources of energy in cell respiration. All carbohydrates contain carbon, hydrogen, and oxygen and are classified as monosaccharides, disaccharides, oligosaccharides, and polysaccharides. *Saccharide* means "sugar," and the prefix indicates how many are present.

Monosaccharides, or single-sugar compounds, are the simplest sugars. Glucose is a **hexose**, or six-carbon, sugar with the formula $C_6H_{12}O_6$ (Fig. 2–6). Fructose and galactose also have the same formula, but the physical arrangement of the carbon, hydrogen, and oxygen atoms in each differs from that of glucose. This gives each hexose sugar a different three-dimensional shape. The honey produced by bees contains fructose and glucose. Sweet fruits contain fructose (glucose does not taste very sweet to us). Galactose is usually part of the disaccharide lactose in milk. The liver is able to change fructose and galactose to glucose, which is then used by cells in the process of cell respiration to produce ATP.

Another type of monosaccharide is the **pentose**, or five-carbon, sugar. These are not involved in energy production but rather are structural components of the nucleic acids. Deoxyribose ($C_5H_{10}O_4$) is part of DNA, which is the genetic material of chromosomes. Ribose ($C_5H_{10}O_5$) is part of RNA, which is essential for protein synthesis. We will return to the nucleic acids later in this chapter.

Disaccharides are double sugars, made of two monosaccharides linked by a covalent bond. When that bond is formed, a molecule of water (H–O–H) is removed, so the general formula of a disaccharide is not quite twice that of a glucose molecule; it is $C_{12}H_{22}O_{11}$. Sucrose, or cane sugar, for example, is made of one glucose and one fructose; it is also found in beets and other vegetables. Lactose is made

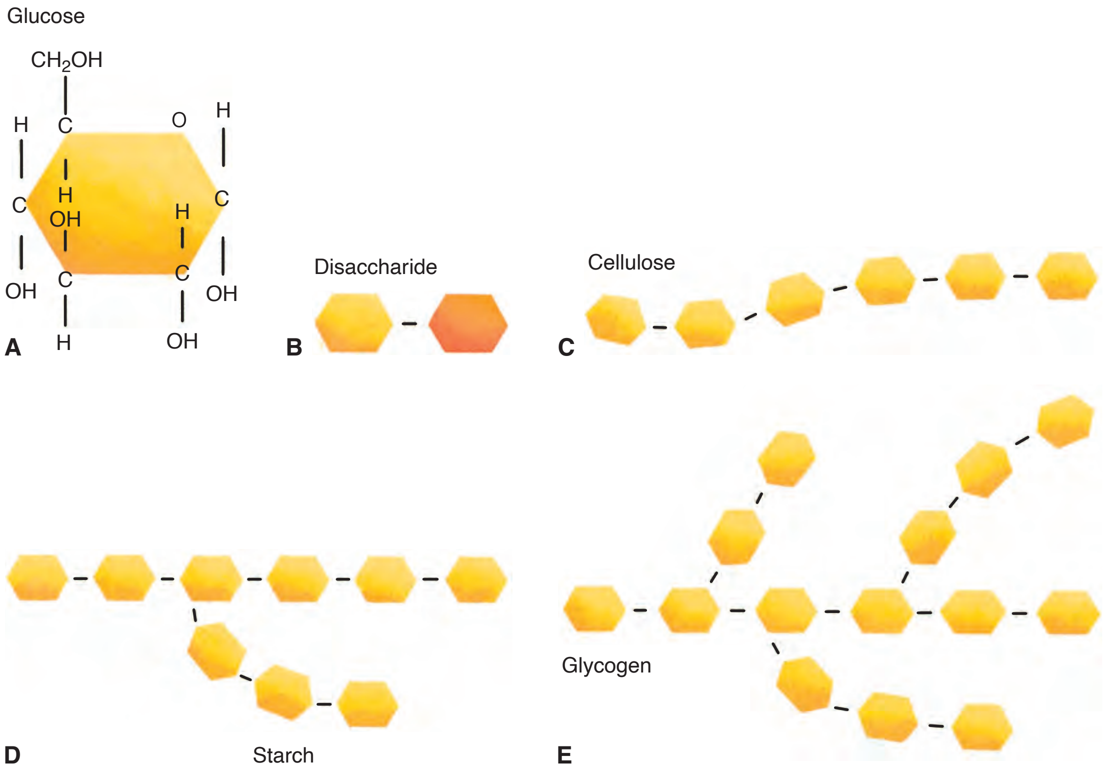


Figure 2–6 Carbohydrates. (**A**) Glucose, depicting its structural formula. (**B**) A disaccharide such as sucrose. (**C**) Cellulose, a polysaccharide. (**D**) Starch, a polysaccharide. (**E**) Glycogen, a polysaccharide. Each hexagon represents a hexose sugar such as glucose.

QUESTION: What is the chemical formula for glucose?

of one glucose and one galactose; it is found in milk, ice cream, yogurt, and other milk products. The grain sugar maltose is made of two glucose molecules. Disaccharides in our food are digested into monosaccharides that are then used for energy production.

The prefix *oligo* means "few"; **oligosaccharides** consist of from 3 to 20 monosaccharides. Unlike other carbohydrates, oligosaccharides are not sources of energy for us because we cannot digest them. In human cells, oligosaccharides are found on the outer surface of cell membranes. Here they serve as **antigens**, which are chemical markers (or "signposts") that identify cells. The A, B, and AB blood types, for example, are the result of oligosaccharide antigens on the outer surface of red blood cell membranes. All of our cells have "self" antigens, which identify the cells that belong in an individual. The presence of "self" antigens on our own cells provides a comparison for the white blood cells of the immune system to use with foreign material; the white blood cells are then able to recognize antigens that are "non-self." Such foreign antigens include bacteria and viruses, and immunity will be a major topic of Chapter 14.

Different oligosaccharides are produced by the cells of the mammary glands and become part of breast milk. These carbohydrates are not meant to nourish the breastfed infant (milk contains lactose for the baby), but rather to encourage the growth of beneficial bacteria in the infant's intestines (the newborn's intestines are sterile, but bacteria arrive with every swallow). Recall from Chapter 1 that such bacteria, our microbiota or normal flora, are believed to contribute to the health of the intestinal tract throughout life, as well as to aspects of immunity. (See also Box 2–3: Vegetables: Tears and Gas.)

Polysaccharides are made of thousands of glucose molecules, bonded in different ways, resulting in different shapes (see Fig. 2–6). **Starches** are branched chains of glucose and are produced by plant cells to store energy. Potatoes, rice, corn, and wheat all contain useful starches. Nearly every human culture has learned to cultivate a major crop to be a source of starch. We consume starches as part of bread, pasta, pizza crust, noodles, French fries, and dumplings, as well as cookies, cakes, and pies. Humans have the digestive enzymes that split the bonds of starch molecules, releasing glucose. The glucose is then absorbed and used by cells to produce ATP.

Glycogen, a highly branched chain of glucose molecules, is our own storage form for glucose. After a meal high in carbohydrates, the blood glucose level rises. If the level were to remain high, glucose would be lost as the kidneys excreted it in urine (this is what happens in diabetes). But with the presence of the hormone insulin, excess glucose in the blood is quickly changed to glycogen and stored in the liver and skeletal muscles. When the blood glucose level decreases between meals, the glycogen is converted back to glucose, which is released into the blood (these reactions are regulated by other hormones). The blood glucose level is kept within normal limits, and cells can take in this glucose to produce energy.

Cellulose is a nearly straight chain of glucose molecules produced by plant cells as part of their cell walls. We have

Box 2–3 | VEGETABLES: TEARS AND GAS

Chopping onions often makes the cook cry. Vegetables that are part of a healthful diet, such as beans, cabbage, broccoli, and cauliflower, give many people the discomfort of intestinal gas and bloating. Why does this happen? By now you know; it's all in their chemistry.

Some of the amino acids in onion cells contain sulfur. Chopping an onion ruptures cells and releases a sulfur compound that vaporizes easily. When this sulfur compound comes in contact with the water that covers the surface of the eye (tears), it dissolves and forms a very dilute sulfuric acid, which stings. The lacrimal (tear) glands are stimulated to produce tears more rapidly, and blinking increases to spread the tears. Both of these responses may help to wash the irritating acid away.

Among many other vegetables, beans and broccoli contain oligosaccharides that we cannot digest. Our intestinal bacteria, however, which are part of our normal flora, especially in the colon, produce enzymes that ferment oligosaccharides. One of the fermentation products is gas (actually several gases, some with unpleasant odors). You may be wondering if "gas-relief" products work. Any that contain the enzyme alpha-galactosidase will prevent this type of gas formation. This enzyme will digest oligosaccharides before they reach the colon bacteria. The oligosaccharides are not fermented, and so gas is not produced.

no enzyme to digest the cellulose we consume as part of vegetables (such as beans, broccoli, and peas), grains, and nuts, so it passes through the digestive tract unchanged. Many raw vegetables and nuts, such as carrots or walnuts, are crunchy; what we are crunching is cellulose. Even fruits that are not especially crunchy, such as peaches or strawberries, contain quite a bit of cellulose. Another name for dietary cellulose is "fiber," and although we cannot use its glucose for energy, it does have a function. **Fiber** provides bulk within the cavity of the large intestine. This promotes efficient **peristalsis**, the waves of contraction that propel undigested material through the colon. A diet low in fiber does not give the colon much exercise, and the muscle tissue of the colon will contract weakly, just as our skeletal muscles will become flabby without exercise. A diet high in fiber provides exercise for the colon muscle and may help prevent chronic constipation. Plant fiber also provides food for our intestinal bacteria; they do have enzymes to break down these complex carbohydrates.

The structure and functions of the carbohydrates are summarized in Table 2–3.

LIPIDS

Lipids contain the elements carbon, hydrogen, and oxygen; some also contain phosphorus. This group of organic compounds includes different types of substances with very

Table 2–3 | **CARBOHYDRATES**

NAME	STRUCTURE	FUNCTION
MONOSACCHARIDES: SINGLE SUGARS		
Glucose	Hexose sugar	■ Most important energy source for cells
Fructose and galactose	Hexose sugar	■ Converted to glucose by the liver and then used for energy production
Deoxyribose	Pentose sugar	■ Part of DNA, the genetic code in the chromosomes of cells
Ribose	Pentose sugar	■ Part of RNA, needed for protein synthesis within cells
DISACCHARIDES: DOUBLE SUGARS		
Sucrose, lactose, and maltose	Two hexose sugars	■ Present in food; digested to monosaccharides, which are then used for energy production
OLIGOSACCHARIDES: FEW SUGARS		
	3 to 20 monosaccharides	■ Form "self" antigens on cell membranes; important to permit the immune system to distinguish "self" from foreign antigens (pathogens) ■ Produced by cells of the mammary glands; encourage growth of beneficial bacteria in the infant's intestinal tract
POLYSACCHARIDES: MANY SUGARS (THOUSANDS)		
Starches	Branched chains of glucose molecules	■ Found in plant foods; digested to monosaccharides and used for energy production
Glycogen	Highly branched chains of glucose molecules	■ Storage form for excess glucose in the liver and skeletal muscles
Cellulose	Straight chains of glucose molecules	■ Part of plant cell walls; provides fiber to promote peristalsis, especially by the colon, and to nourish intestinal microbiota

different functions. We will consider three types: true fats, phospholipids, and steroids (Fig. 2–7).

True fats (also called neutral fats) are made of one molecule of glycerol and one, two, or three fatty acid molecules. Glycerol is a small 3-carbon molecule ($C_3H_8O_3$). A fatty acid is a long molecule that has an even number of carbons, from 12 to 24, bonded to hydrogens, with the first carbon a carboxyl group: COOH. If three fatty acid molecules are bonded to a single glycerol, a **triglyceride** is formed. Two fatty acids and a glycerol form a **diglyceride**, and one fatty acid and a glycerol form a **monoglyceride**.

The fatty acids in a true fat may be **saturated** or **unsaturated**. Refer to Fig. 2–7 and notice that one of the fatty acids has single covalent bonds between all of its carbon atoms. Each of these carbons is then bonded to the maximum number of hydrogens; this is a saturated fatty acid, meaning saturated with hydrogen. The other fatty acids shown have one or more (poly) double covalent bonds between their carbons and less than the maximum number of hydrogens; these are unsaturated fatty acids. Many triglycerides contain both saturated and unsaturated fatty acids, and although not as precise, it is often easier to speak of saturated and unsaturated *fats*,

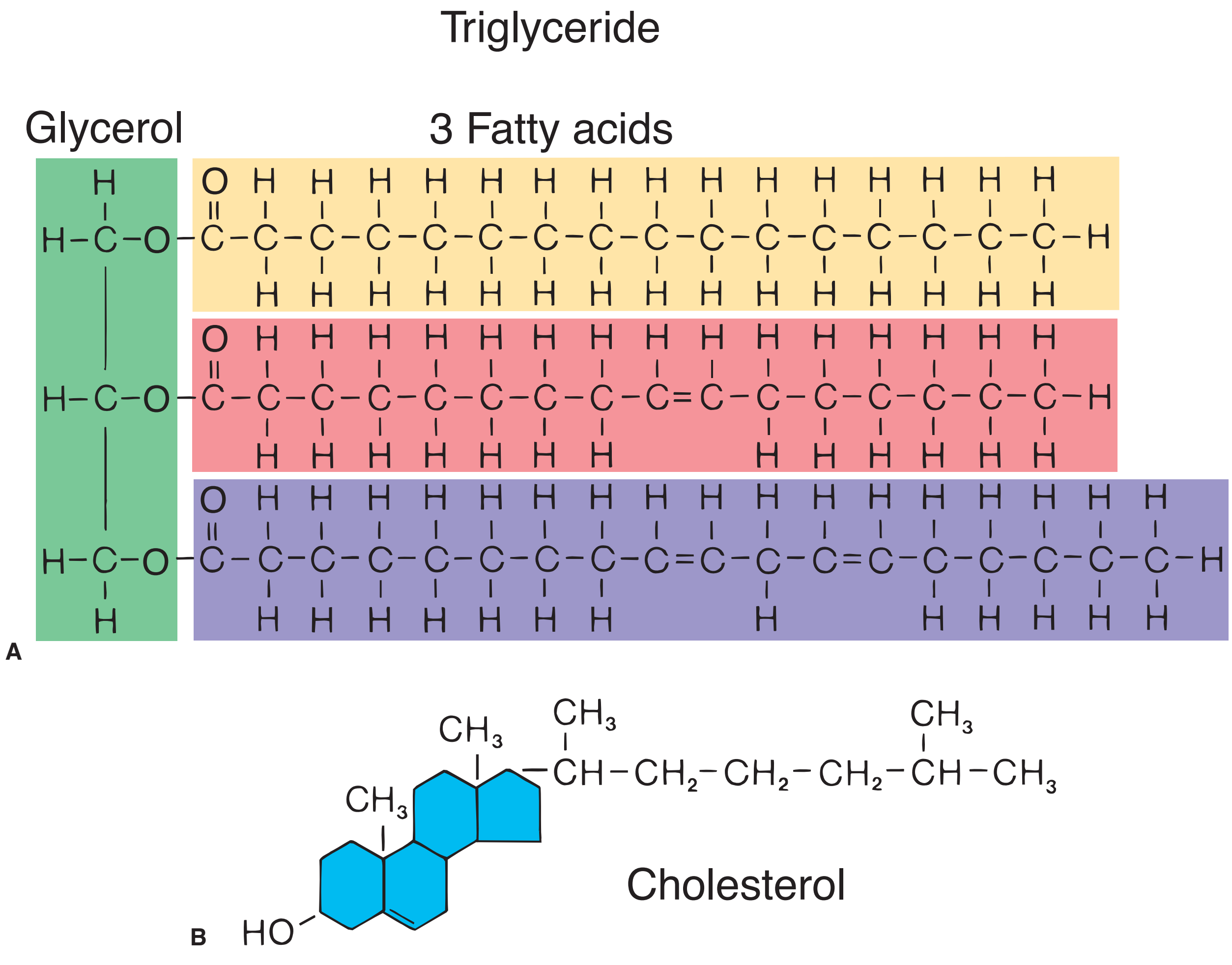


Figure 2–7 Lipids. (**A**) A triglyceride made of one glycerol and three fatty acids. (**B**) The steroid cholesterol. The hexagons and pentagon represent rings of carbon and hydrogen.

QUESTION: What would a diglyceride look like?

indicating the predominance of one or the other type of fatty acid.

At room temperature, saturated fats are often in solid form, whereas unsaturated fats are often (not always) in liquid form. Saturated fats tend to be found in animal-based foods such as beef, pork, chicken, eggs, and cheese, but palm oil and coconut oil are also saturated. Unsaturated fats are found in other plant oils such as corn oil, sunflower oil, and safflower oil, but certain fish oils are also unsaturated, and even pork contains some unsaturated fatty acids.

Unsaturated fats may be changed to saturated fats in order to give packaged foods a more pleasing texture or taste, or to allow them to be stored longer without refrigeration (a longer shelf life). These are hydrogenated fats (meaning that hydrogens have been added), also called trans fats. Trans fats contribute significantly to **atherosclerosis** of arteries; that is, abnormal cholesterol deposits in the lining that may clog arteries, especially the coronary arteries of the heart. As of early 2014, the Food and Drug Administration was considering banning the use of trans fats in prepared foods. (See also Box 2–4: Lipids in the Blood.)

The triglyceride forms of true fats are a storage form for excess food; that is, they are stored energy (potential energy). Any type of food consumed in excess of the body's caloric needs will be converted to fat and stored in adipose tissue. Most adipose tissue is subcutaneous, between the skin and muscles. Some organs, however, such as the eyes and kidneys, are enclosed in a layer of fat that acts as a cushion to absorb shock. (We will consider the other functions of adipose tissue in Chapter 4.)

Phospholipids are diglycerides with a phosphate group (PO_4) in the third bonding site of glycerol. Although similar in structure to the true fats, phospholipids are not stored energy but rather structural components of cells. Lecithin is a phospholipid that is part of our **cell membranes** (see Fig. 3–1 in Chapter 3; each phospholipid molecule looks like a sphere with two tails; the sphere is the glycerol and phosphate, the tails are the two fatty acids). Another phospholipid is **myelin**, which forms the myelin sheath around nerve cells and provides electrical insulation for nerve impulse transmission.

The structure of **steroids** is very different from that of the other lipids. **Cholesterol** is an important steroid; it is made of four rings of carbon and hydrogen (not fatty acids and glycerol) and is shown in Fig. 2–7. The liver synthesizes cholesterol, in addition to the cholesterol we eat in food. Only animal foods such as beef, pork, milk products, and egg yolks contain cholesterol. Vegetarians do not have cholesterol in their diet and depend upon synthesis by the liver. Cholesterol is

Box 2–4 | LIPIDS IN THE BLOOD

Triglycerides and cholesterol are transported in the blood in combination with proteins. Such molecules made by the small intestine are called chylomicrons. Those made by the liver are called lipoproteins and are categorized by their density, which reflects the proportion of protein to cholesterol.

Low-density lipoproteins (LDLs, which are low in protein and high in cholesterol) transport cholesterol to the tissues, where it is used to synthesize cell membranes or secretions. LDLs are also called "bad cholesterol" because in this form the cholesterol is more likely to be deposited in the walls of blood vessels, leading to atherosclerosis.

High-density lipoproteins (HDLs, which are higher in protein and lower in cholesterol than LDLs) transport cholesterol from the tissues to the liver. HDLs are also called "good cholesterol" because in this form cholesterol is more easily removed from the blood by the liver and excreted in bile.

A diet low in total fat, with most of it unsaturated fat, tends to raise HDL levels and lower LDL levels. These levels are believed to delay the development of atherosclerosis and coronary artery disease. A simple blood test called a lipid profile (or lipid panel) can determine levels of total cholesterol, triglycerides, HDLs, and LDLs. A high HDL level, above 50 mg/dL, is considered good (above 60 mg/dL is considered even more protective), as is a low LDL level, below 100 mg/dL.

Other factors contribute to coronary artery disease, such as heredity, smoking, being overweight, and lack of exercise. Diet alone cannot prevent atherosclerosis. However, a diet low in total fat and high in polyunsaturated fats is a good start.

another significant component of cell membranes and is the precursor (raw material) for the synthesis of other steroids. In the ovaries or testes, cholesterol is used to synthesize the steroid hormones estrogen or testosterone, respectively. A form of cholesterol in the skin is changed to vitamin D on exposure to sunlight. Liver cells use cholesterol for the synthesis of bile salts, which emulsify fats in digestion. Despite its link to coronary artery disease and heart attacks, cholesterol is an essential substance for human beings.

The structure and functions of lipids are summarized in Table 2–4.

PROTEINS

Proteins are made of smaller subunits or building blocks called **amino acids**, which all contain the elements carbon, hydrogen, oxygen, and nitrogen. Some amino acids contain sulfur, which permits the formation of disulfide bonds in proteins such as insulin and antibodies. There are about 20 amino acids that make up human proteins. We obtain these amino acids from animal proteins such as beef, chicken, pork, and fish, and from plant proteins such as those found in beans, peas, nuts, corn, and other grains.

The structure of amino acids is shown in Fig. 2–8, and you will notice that they all have several parts in common. Each amino acid has a central carbon atom covalently bonded to an atom of hydrogen, an amino group (NH_2), and a carboxyl group (COOH). At the fourth bond of the central carbon is the variable portion of the amino acid, represented by R. The R group may be a single hydrogen atom, or a CH_3 group, or a more complex configuration of carbon and hydrogen and perhaps sulfur. This gives each of the 20 amino acids a slightly different physical shape. A bond between two amino acids is called a **peptide bond**, and a short chain of amino acids linked by peptide bonds is a **polypeptide**.

A protein may consist of from 50 to thousands of amino acids. The sequence of the amino acids is specific and unique for each protein and is called its primary structure. This unique sequence, and the hydrogen bonds and disulfide bonds formed within the amino acid chain, determines how the protein will be folded to complete its synthesis. The folding may be simple, a helix (coil) or pleated sheet called the secondary structure, or more complex folding may occur to form a globular protein called the tertiary structure. Myoglobin, found in muscles, is a globular protein (Fig. 2–8E). When complete, each protein has a characteristic three-dimensional shape, which in turn determines its function. Some proteins consist of more than one amino acid chain (quaternary structure). Hemoglobin, for example, has four amino acid chains (see Box 3–2 in Chapter 3). Notice that myoglobin contains an atom of iron (a hemoglobin molecule has four iron atoms). Some proteins require a trace element such as iron or zinc to complete their structure and permit them to function properly.

Table 2–4 | LIPIDS

NAME	STRUCTURE	FUNCTION
True fats	A triglyceride consists of three fatty acid molecules bonded to a glycerol molecule (some are monoglycerides or diglycerides)	■ Storage form for excess food molecules in subcutaneous tissue ■ Cushion organs such as the eyes and kidneys
Phospholipids	Diglycerides with a phosphate group bonded to the glycerol molecule	■ Part of cell membranes (lecithin) ■ Form the myelin sheath to provide electrical insulation for neurons
Steroids (cholesterol)	Four carbon–hydrogen rings	■ Part of cell membranes ■ Converted to vitamin D in the skin on exposure to UV rays of the sun ■ Converted by the liver to bile salts, which emulsify fats during digestion ■ Precursor for the steroid hormones such as estrogen in women (ovaries) or testosterone in men (testes)

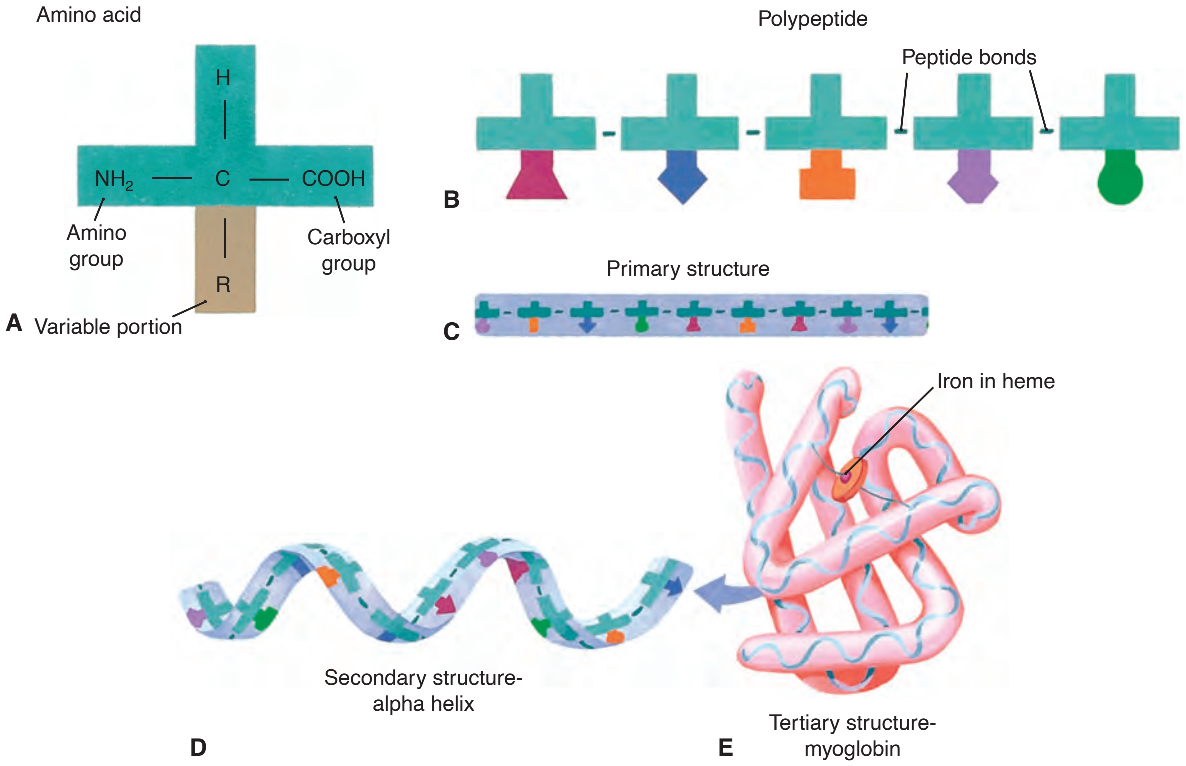


Figure 2–8 Amino acid and protein structure. (**A**) The structural formula of an amino acid. The "R" represents the variable portion of the molecule. (**B**) A polypeptide. Several amino acids, represented by different shapes, are linked by peptide bonds. (**C**) The primary structure of a protein. (**D**) The secondary structure of a protein. (**E**) The tertiary structure of the protein myoglobin. See text for further description.

QUESTION: What mineral is part of myoglobin, and what is its function?

Our body proteins have many functions; some of these are listed in Table 2–5 and will be mentioned again in later chapters. Although we usually do not think of protein as an energy food, if our diet includes more amino acids than are necessary for our protein synthesis, those excess amino acids will be converted to simple carbohydrates, or even to fat, to be stored as potential energy. (See Box 2–5: A Protein Mystery: Prions for a discussion of disease-causing proteins.) One very important function of proteins will be discussed further here: the role of proteins as enzymes.

Enzymes

Enzymes are **catalysts**, which means that they speed up chemical reactions without the need for an external source of energy such as heat. The many reactions that take place within the body are catalyzed by specific enzymes; all of these reactions must take place at body temperature.

The way in which enzymes function as catalysts is called the **active site theory**. Keep in mind that a "theory" is not a guess; a scientific theory is the best explanation for all the available evidence. All the evidence of enzyme functioning supports the active site theory, which states that the shape of an enzyme determines its function. The specific function also includes the shapes of the reacting molecules, called **substrates**. A simple synthesis reaction is depicted in Fig. 2–9A. Notice that the enzyme has a specific shape, as do the substrate molecules. The active site of the enzyme is the

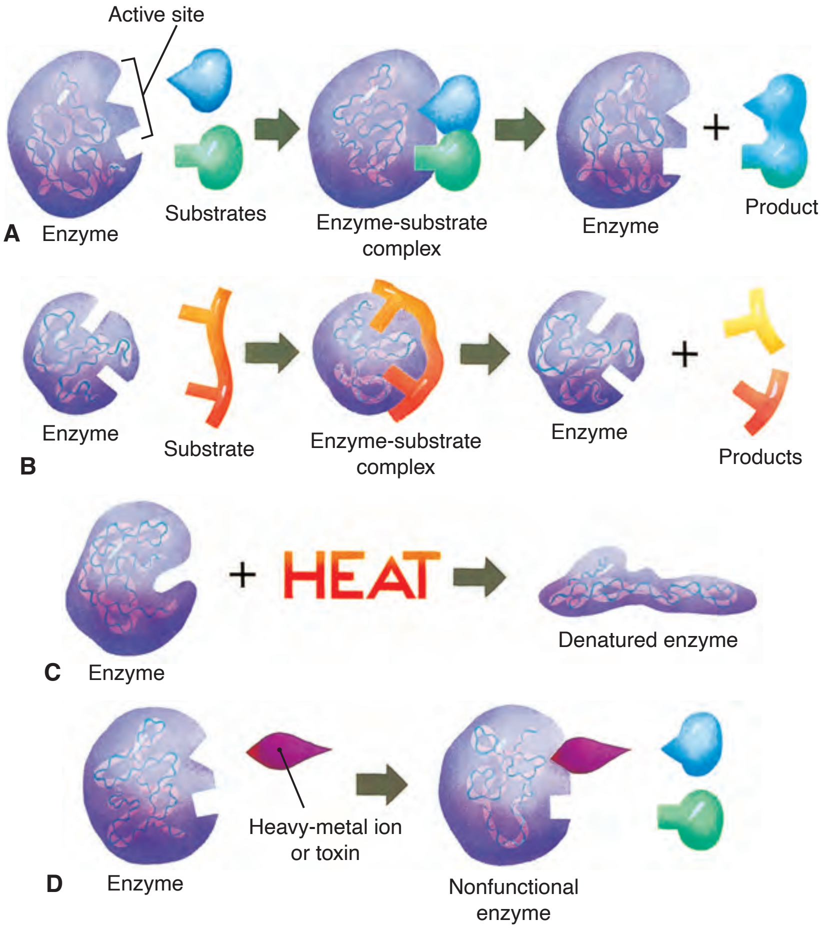


Figure 2–9 Active site theory. (**A**) Synthesis reaction. (**B**) Decomposition reaction. (**C**) The effect of heat. (**D**) The effect of poisons. See text for description.

QUESTION: Which of these four pictures best represents the effect of an acidic pH on an enzyme, and why?

Table 2–5 | **FUNCTIONS OF PROTEINS**

TYPE OF PROTEIN	FUNCTION
Structural proteins	■ Form channels, transporters, intercellular junctions, and receptor sites in cell membranes ■ Keratin—part of hair, nails, and the epidermis of the skin ■ Collagen—part of tendons, ligaments, and the dermis of the skin
Hormones	■ Insulin—enables cells to take in glucose; lowers blood glucose level ■ Growth hormone—increases protein synthesis and cell division
Hemoglobin	■ Enables red blood cells to carry oxygen
Myoglobin	■ Stores oxygen in muscle cells
Antibodies	■ Produced by lymphocytes (white blood cells); label pathogens for destruction
Myosin and actin	■ Muscle structure and contraction ■ Part of the cytoskeleton that gives shape to cells and permits movement
Enzymes	■ Catalyze reactions: synthesis, decomposition, energy production, cellular reproduction

Box 2–5 | A PROTEIN MYSTERY: PRIONS

Prions are proteinaceous infectious particles, the cause of lethal diseases of the nervous system in people and animals. Besides Creutzfeldt-Jakob disease (CJD), mad-cow disease is perhaps the best known; its formal name is bovine spongiform encephalopathy (BSE). The name tells us about the disease: *Encephalopathy* means that the brain is affected, and *spongiform* indicates that brain tissue becomes spongy, or full of holes. People may acquire BSE by eating beef contaminated with infected cow brain tissue. They develop what is called variant Creutzfeldt-Jakob disease. Variant CJD is characterized by loss of coordination, loss of memory and personality, and death within a few months. There is no treatment.

How do prions cause this disease? We do not yet have the entire answer. We do know that prions are natural proteins; they function in nerve tissue and seem to be involved in creating myelin sheaths and contributing to memory. But just like any other part of a living organism, they can malfunction. Malfunctioning prions are believed to change the structure of other brain proteins, causing misfolding. Misfolded proteins are treated like old or damaged proteins: The cell uses cleanup enzymes and mechanisms to get rid of them, but the excess of faulty proteins overburdens these mechanisms and brings about deterioration of brain tissue.

Unfortunately, we do not know how to destroy prions. Prions are not living; they do not contain genetic material or carry out processes that might be disrupted by antibiotics or antiviral medications. Cooking does not seem to affect them. Standard sterilization practices that kill bacteria and viruses do not seem to inactivate prions.

Prevention of prion disease depends on keeping animal brain tissue from contaminating meat destined for human or animal consumption. In Great Britain, where the human form of mad-cow disease emerged and killed nearly 100 people, butchering practices are now stringently regulated. As of this writing, infected cattle have been found in North America, but no cases of variant CJD have occurred in people.

part that matches the shapes of the substrates. The substrates must “fit” into the active site of the enzyme, and temporary bonds may form between the enzyme and the substrate. This is called the enzyme–substrate complex. In this case, two substrate molecules are thus brought close together so that chemical bonds are formed between them, creating a new compound. The product of the reaction, the new compound, is then released, leaving the enzyme itself unchanged and able to catalyze another reaction of the same type.

The reaction shown in Fig. 2–9B is a decomposition reaction. As the substrate molecule bonds to the active site of the enzyme, strain is put on its internal bonds, which break, forming two product molecules and again leaving the enzyme unchanged. Each enzyme is specific in that it will catalyze only one type of reaction. An enzyme that digests the protein in food, for example, has the proper shape for that reaction but cannot digest starches. For starch digestion, another enzyme with a differently shaped active site is needed. Thousands of chemical reactions take place within the body, and therefore we have thousands of enzymes, each with its own shape and active site.

The ability of enzymes to function may be limited or destroyed by changes in the intracellular or extracellular fluids in which they are found. Changes in pH and temperature are especially crucial. Recall that the pH of intracellular fluid is approximately 6.8 to 7.0 and that a decrease in pH means that more H^+ ions are present. If pH decreases significantly, the excess H^+ ions will react with the active sites of cellular enzymes, change their shapes, and prevent them from catalyzing reactions. This is why a state of acidosis may cause the death of cells—the cells’ enzymes are unable to function properly.

With respect to temperature, most human enzymes have their optimum functioning in the normal range of body temperature: 97° to 99°F (36° to 38°C). A temperature of 106°F, a high fever, may break the chemical bonds that maintain the shapes of enzymes (see Fig. 2–9C). If an enzyme loses its shape, it is said to be **denatured**, and a denatured enzyme is unable to function as a catalyst. Some human enzymes, when denatured by a high fever, may revert to their original shapes if the fever is lowered quickly. Others, however, will not. (An example of irreversible denaturation is a hard-boiled egg; the proteins in the egg white and yolk will never revert to what they were in the original egg.) A high fever may cause brain damage or death because enzymes in the brain have become permanently denatured.

You already know that metals such as lead and mercury are harmful to humans and that both may cause serious damage to the nervous system and other body tissues. These heavy metals are harmful to us because they are very reactive and block the actions of our enzymes. Fig. 2–9D depicts what happens. Notice that the heavy metal ion bonds with part of the active site of the enzyme and changes its shape. The substrate molecule cannot fit, and the enzyme is useless. Many other chemicals are poisonous to us for the very same reason: They destroy the functioning of our enzymes, and essential reactions cannot take place.

NUCLEIC ACIDS

DNA and RNA

The **nucleic acids**, **DNA** (deoxyribonucleic acid) and **RNA** (ribonucleic acid), are large molecules made of smaller subunits called nucleotides. A **nucleotide** consists of a pentose sugar, a phosphate group, and one of several nitrogenous bases. In DNA nucleotides, the sugar is deoxyribose, and the bases are adenine, guanine, cytosine, or thymine. In RNA nucleotides, the sugar is ribose, and the bases are adenine, guanine, cytosine, or uracil. DNA and RNA molecules are shown in Fig. 2–10. Notice that DNA looks somewhat like a twisted ladder; this ladder is two strands of nucleotides called a double helix (two coils). Alternating phosphate and sugar molecules form the uprights of the ladder, and pairs of nitrogenous bases form the rungs. The size of the bases and the number of hydrogen bonds each can form the complementary base pairing of the nucleic acids. In DNA, adenine is always paired with thymine (with two hydrogen bonds), and guanine is always paired with cytosine (with three hydrogen bonds).

DNA makes up the chromosomes of cells and is therefore the **genetic code** for hereditary characteristics. The sequence of bases in the DNA strands is actually a code for the many kinds of proteins living things produce; the code is the same in plants, other animals, and microbes. The sequence of bases for one protein is called a gene. Human genes are the codes for the proteins produced by human cells (though many of these genes are also found in all other forms of life—we are all very much related). The functioning of DNA will be covered in more detail in the next chapter.

RNA is often a single strand of nucleotides (see Fig. 2–10), with uracil nucleotides in place of thymine nucleotides. RNA is synthesized from DNA in the nucleus of a cell, and there are several forms. All carry out their functions in the cytoplasm. RNA copies the genetic code from DNA and helps assemble amino acids into proteins. Protein synthesis will also be discussed in the following chapter.

ATP

ATP (adenosine triphosphate) is a specialized nucleotide that consists of the base adenine, the sugar ribose, and three phosphate groups (see Fig. 2–11). Mention has already been made of ATP as a product of cell respiration that contains biologically useful energy. ATP is one of several “energy transfer” molecules within cells, transferring the potential energy in food molecules to cell processes. When a molecule of glucose is broken down into carbon dioxide and water with the release of energy, the cell uses some of this energy to synthesize ATP. Present in cells are molecules of ADP (adenosine diphosphate) and free phosphate groups. The energy released from glucose is used to loosely bond a third phosphate to ADP, forming ATP (moving right to left in Fig. 2–11). When the bond of this third phosphate is again broken and energy is released (moving left to right in Fig. 2–11), ATP then becomes the energy source for cell processes such as mitosis, muscle contraction, or protein synthesis for growth and repair.

All cells have enzymes that can remove the third phosphate group from ATP to release its energy, forming ADP and phosphate. As cell respiration continues, ATP is resynthesized from ADP and phosphate. ATP formation to trap energy from food and ATP breakdown to release energy for cell processes is a continuing cycle in cells.

The structure and functions of the nucleic acids are summarized in Table 2–6.

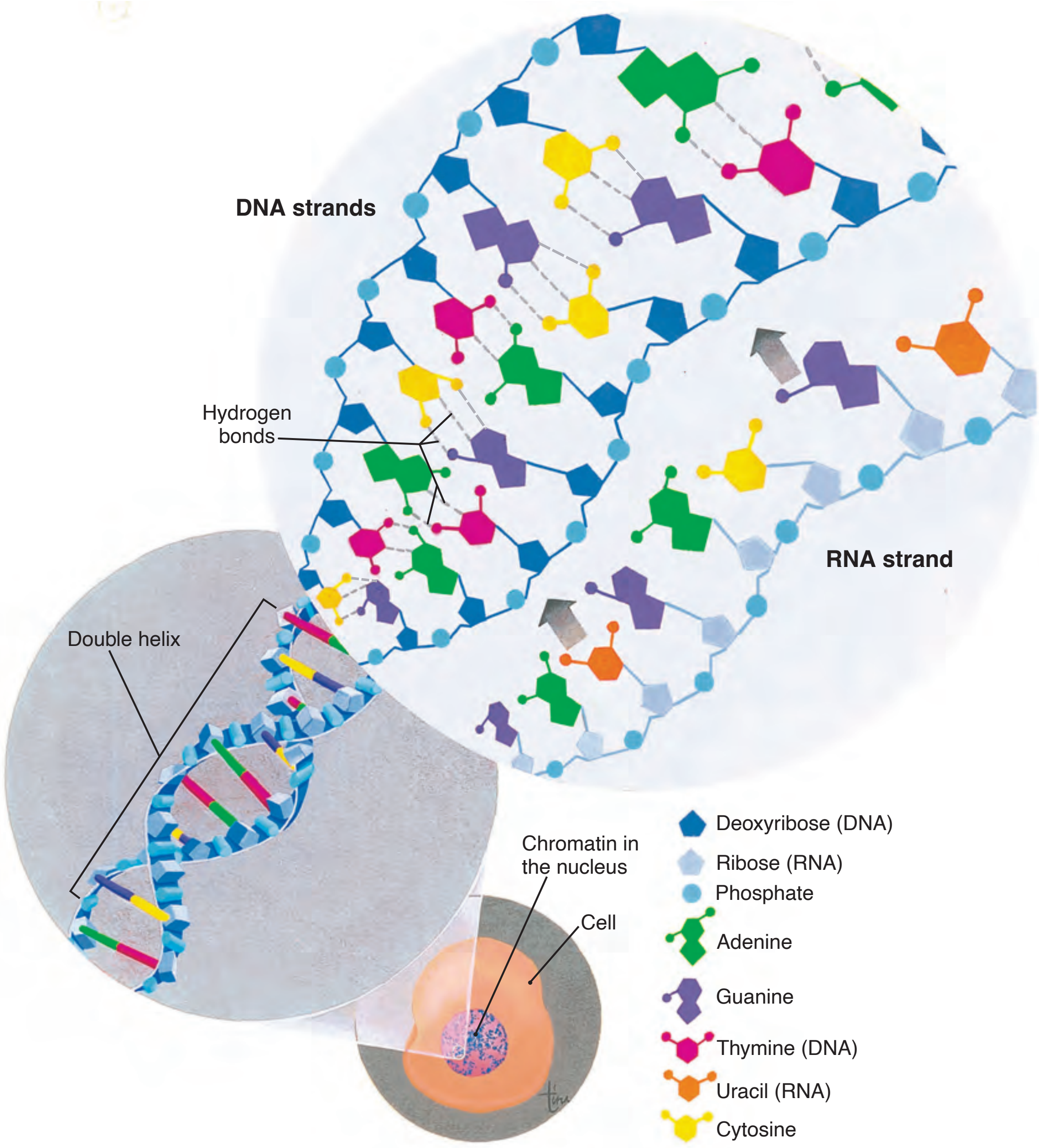


Figure 2–10 DNA and RNA. Both molecules are shown, with each part of a nucleotide represented by its shape and in a different color. Note the complementary base pairing of DNA (A–T and G–C). When RNA is synthesized, it is a complementary copy of half the DNA molecule (with U in place of T).

QUESTION: Why can't adenine pair with guanine to form a rung of the DNA ladder?

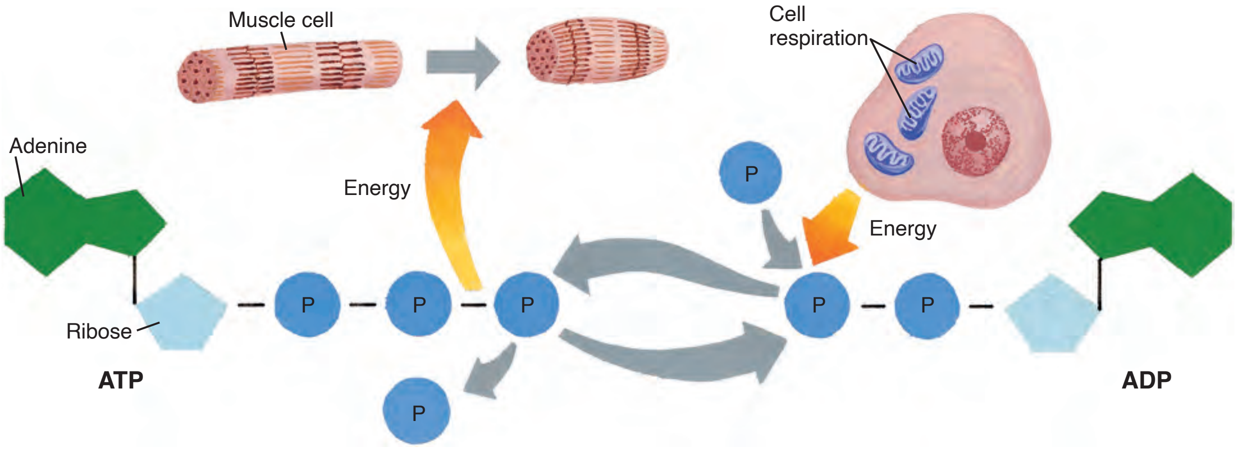


Figure 2–11 ATP. A molecule of ATP is shown on the left, and ADP + phosphate is shown on the right. Notice that this is a cycle.

QUESTION: The energy from ATP is being used here for contraction of a muscle cell. What else may such energy be used for?

Table 2–6 | NUCLEIC ACIDS

NAME	STRUCTURE	FUNCTION
DNA (deoxyribonucleic acid)	A double helix of nucleotides; adenine paired with thymine, and guanine paired with cytosine; the two strands of the helix are connected by hydrogen bonds	■ Found in the chromosomes in the nucleus of a cell ■ The sequence of bases is the genetic code for hereditary characteristics
RNA (ribonucleic acid)	A single strand of nucleotides; adenine, guanine, cytosine, and uracil	■ Copies the genetic code of DNA to direct protein synthesis in the cytoplasm of cells ■ Contributes to the assembly of amino acids into proteins
ATP (adenosine triphosphate)	A single adenine nucleotide with three phosphate groups	■ An energy-transferring molecule ■ Formed when cell respiration releases energy from food molecules ■ Used for energy-requiring cellular processes

SUMMARY

Chemicals may be inorganic, such as water, oxygen, and iron, or organic, such as carbohydrates, lipids, proteins, and nucleic acids. All of the chemicals we have just described are considered to be nonliving, even though they are essential parts of all living organisms. The cells of our bodies are precise arrangements of these nonliving chemicals and yet are considered living matter. The cellular level, therefore, is the next level of organization we will examine.

STUDY OUTLINE

Elements

1. Elements are the simplest chemicals, which make up all matter.
2. Carbon, hydrogen, oxygen, nitrogen, phosphorus, sulfur, and calcium make up 99% of the human body.
3. Elements combine in many ways to form molecules, both inorganic and organic.

Atoms (see Fig. 2–1)

1. An atom is the smallest part of an element that still retains the characteristics of the element.
2. Atoms consist of positively and negatively charged particles and neutral (or uncharged) particles.
   a. Protons have a positive charge and are found in the nucleus of the atom.
   b. Neutrons have no charge and are found in the nucleus of the atom.
   c. Electrons have a negative charge and orbit the nucleus.
3. The number and arrangement of electrons give an atom its bonding capabilities.

Chemical Bonds

1. An ionic bond involves the loss of electrons by one atom and the gain of these electrons by another atom: Ions are formed that attract one another (see Fig. 2–2).
   a. Cations are ions with positive charges: Na^+, Ca^{+2}.
   b. Anions are ions with negative charges: Cl^-, HCO_3^-.
   c. Inorganic salts, acids, and bases are formed by ionic bonding.
   d. In water, many ionic bonds break; dissociation releases ions for other reactions.
2. A covalent bond involves the sharing of electrons between two atoms (see Fig. 2–3).
   a. Oxygen gas (O_2) and water (H_2O) are covalently bonded molecules.
   b. Carbon always forms covalent bonds; these are the basis for the organic compounds.
   c. Covalent bonds are not weakened in an aqueous solution.
3. A disulfide bond is a covalent bond between two sulfur atoms in a protein; it helps maintain the three-dimensional shape of proteins such as insulin and antibodies.
4. A hydrogen bond is the attraction of a covalently bonded hydrogen (slightly positive) to a nearby oxygen or nitrogen atom (slightly negative).
   a. The three-dimensional shape of proteins and nucleic acids is maintained by hydrogen bonds.
   b. Water is cohesive and adhesive because of hydrogen bonds.

Chemical Reactions

1. A change brought about by the formation or breaking of chemical bonds.
2. Synthesis—bonds are formed to join two or more molecules.
3. Decomposition—bonds are broken within a molecule.
4. Within cells, the products of decomposition reactions are often recycled for synthesis reactions.

Inorganic Compounds of Importance

1. Water—makes up 55% to 70% of the body.
    - **a.** Solvent—for transport of nutrients in the blood and excretion of wastes in urine.
    - **b.** Lubricant—mucus in the digestive tract.
    - **c.** Temperature stabilizer—changes temperature slowly, preventing sudden changes in body temperature; absorbs body heat in evaporation of sweat.
    - **d.** Water compartments—the locations of water within the body (see Fig. 2–4).
        - — Intracellular—within cells; 65% of total body water.
        - — Extracellular—35% of total body water
            1) Plasma—in blood vessels.
            2) Lymph—in lymphatic vessels.
            3) Tissue fluid—in tissue spaces between cells.
            4) Specialized fluids in joints, the eyes, and the central nervous system.
2. Oxygen—21% of the atmosphere.
    - **a.** Essential for cell respiration: the breakdown of food molecules to release energy.
3. Carbon dioxide
    - **a.** Produced as a waste product of cell respiration.
    - **b.** Must be exhaled; excess CO_2 in body fluids causes acidosis.
4. Cell respiration—the energy-producing processes of cells.
    - **a.** Glucose + $O_2 \rightarrow CO_2 + H_2O$ + ATP + heat
    - **b.** This is why we breathe: to take in oxygen to break down food to produce energy, and to exhale the CO_2 produced.
5. Trace elements—minerals needed in small amounts (see Table 2–2).
6. Acids, bases, and pH
    - **a.** The pH scale ranges from 0 to 14; 7 is neutral. Below 7 is acidic, and above 7 is alkaline.
    - **b.** An acid increases the H^+ ion concentration of a solution; a base decreases the H^+ ion concentration (or increases the OH^- ion concentration) (see Fig. 2–5).
    - **c.** The pH range within cells is about 6.8 to 7.0. The normal pH range of blood is 7.35 to 7.45. Normal metabolism tends to make body fluids more acidic.
    - **d.** Buffer systems maintain normal pH by reacting with strong acids or strong bases to change them to substances that do not greatly change pH.
    - **e.** The bicarbonate buffer system consists of $NaHCO_3$ to react with strong acids and H_2CO_3 to react with strong bases (ratio about 20:1).

Organic Compounds of Importance

1. Carbohydrates (see Table 2–3 and Fig. 2–6).
    - **a.** Monosaccharides are simple sugars. Glucose, a hexose sugar ($C_6H_{12}O_6$), is the primary energy source for cell respiration. Fructose and galactose have the same chemical formula.
        - — Pentose sugars are part of the nucleic acids DNA and RNA.
    - **b.** Disaccharides are made of two hexose sugars. Sucrose, lactose, and maltose are digested to monosaccharides and used for cell respiration.
    - **c.** Oligosaccharides consist of from 3 to 20 monosaccharides.
        - — On cell membranes they are antigens that identify cells as "self."
        - — In breast milk they nourish an infant's beneficial intestinal bacterial population.
    - **d.** Polysaccharides are made of thousands of glucose molecules.
        - — Starches are plant products broken down in digestion to glucose.
        - — Glycogen is the form in which glucose is stored in the liver and muscles to help regulate the blood glucose level.
        - — Cellulose, the fiber of plant cells, cannot be digested but promotes efficient peristalsis in the colon.

2. Lipids (see Table 2–4 and Fig. 2–7).
    - **a.** True fats are made of fatty acids and glycerol; triglycerides are a storage form for potential energy in adipose tissue. The eyes and kidneys are cushioned by fat. Fatty acids may be saturated (maximum number of hydrogens) or unsaturated (less than the maximum number of hydrogens). Saturated fats and hydrogenated or trans fats contribute to atherosclerosis.
    - **b.** Phospholipids are diglycerides such as lecithin that are part of cell membranes. Myelin is a phospholipid that provides electrical insulation for nerve cells.
    - **c.** Steroids consist of four rings of carbon and hydrogen. Cholesterol, produced by the liver and consumed in food, is the basic steroid from which the body manufactures others: steroid hormones, vitamin D, and bile salts.
3. Proteins
    - **a.** Amino acids are the subunits of proteins; 20 amino acids make up human proteins. Peptide bonds join amino acids to one another (see Fig. 2–8).
    - **b.** A protein consists of from 50 to thousands of amino acids in a specific sequence (primary structure) that is folded into a specific shape (secondary and tertiary structures). Some proteins are made of two or more amino acid chains (quaternary structure); some proteins contain trace elements.
    - **c.** Protein functions—see Table 2–5.
    - **d.** Amino acids in excess of the need for protein synthesis are converted to simple carbohydrates or to fat, for energy production.
    - **e.** Enzymes are catalysts, which speed up reactions without additional energy. The active site theory is based on the shapes of the enzyme and the substrate molecules: These must "fit" (see Fig. 2–9). The enzyme remains unchanged after the product of the reaction is released. Each enzyme is specific for one type of reaction. The functioning of enzymes may be disrupted by changes in pH or body temperature, or by the presence of a poison, which changes the shape of the active sites of enzymes.
4. Nucleic acids (see Table 2–6 and Fig. 2–10).
    - **a.** Nucleotides are the subunits of nucleic acids. A nucleotide consists of a pentose sugar, a phosphate group, and a nitrogenous base.
    - **b.** DNA is a double strand of nucleotides, coiled into a double helix, with complementary base pairing: A–T and G–C. DNA makes up the chromosomes of cells and is the genetic code for the synthesis of proteins.
    - **c.** RNA is a single strand of nucleotides, synthesized from DNA, with U in place of T. RNA functions in protein synthesis; several forms function in the process of protein synthesis in the cytoplasm of a cell.
    - **d.** ATP is a nucleotide that is specialized to trap and transfer energy (see Fig. 2–11). Energy released from food in cell respiration is used to synthesize ATP from ADP + P. When cells need energy, ATP is broken down to ADP + P and the energy is transferred to cell processes.

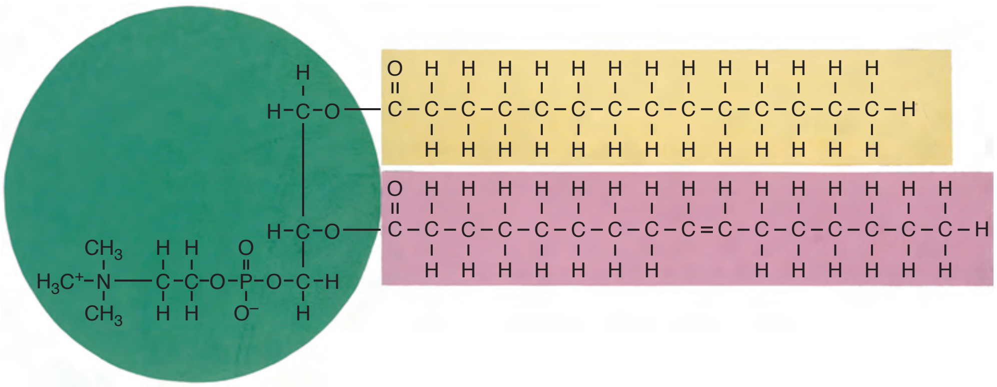
REVIEW QUESTIONS

1. State the chemical symbol for each of the following elements: sodium, potassium, iron, calcium, oxygen, carbon, hydrogen, copper, and chlorine. (p. 28)
2. Explain, in terms of their electrons, how an atom of sodium and an atom of chlorine form a molecule of sodium chloride. (p. 30)
3. **a.** Explain, in terms of their electrons, how an atom of carbon and two atoms of oxygen form a molecule of carbon dioxide. (p. 34)
   b. Explain the functions of hydrogen bonds.
   c. Explain the function of disulfide bonds.
4. Name the subunits (smaller molecules) of which each of the following is made: DNA, glycogen, a true fat, and a protein. (pp. 47, 39, 41, 43)
5. State precisely where in the body each of these fluids is found: plasma, intracellular water, lymph, and tissue fluid. (p. 33)
6. Explain why it is important to the body that water changes temperature slowly. (p. 33)
7. Describe two ways in which the solvent ability of water is important to the body. (pp. 32–33)
8. Name the organic molecule with each of the following functions: (p. 40)
   - **a.** The genetic code in chromosomes
   - **b.** "Self" antigens in our cell membranes
   - **c.** The storage form for glucose in the liver
   - **d.** The storage form for excess food in adipose tissue
   - **e.** The precursor molecule for the steroid hormones
   - **f.** The undigested part of food that promotes peristalsis
   - **g.** The sugars that are part of the nucleic acids
9. State the summary equation of cell respiration. (p. 34)
10. State the role or function of each of the following in cell respiration: CO_2, glucose, O_2, heat, and ATP. (p. 35)
11. State a specific function of each of the following in the human body: Ca, Fe, Na, I, and Co. (p. 35)
12. Explain, in terms of relative concentrations of H^+ ions and OH^- ions, each of the following: acid, base, and neutral substance. (pp. 36–37)
13. State the normal pH range of blood. (p. 36)
14. Complete the following equation, and state how each of the products affects pH: (pp. 36–37)

    $HCl + NaHCO_3 \rightarrow$ _______ + _______
15. Explain the active site theory of enzyme functioning. (p. 44)
16. Explain the difference between a synthesis reaction and a decomposition reaction. (pp. 44–46)

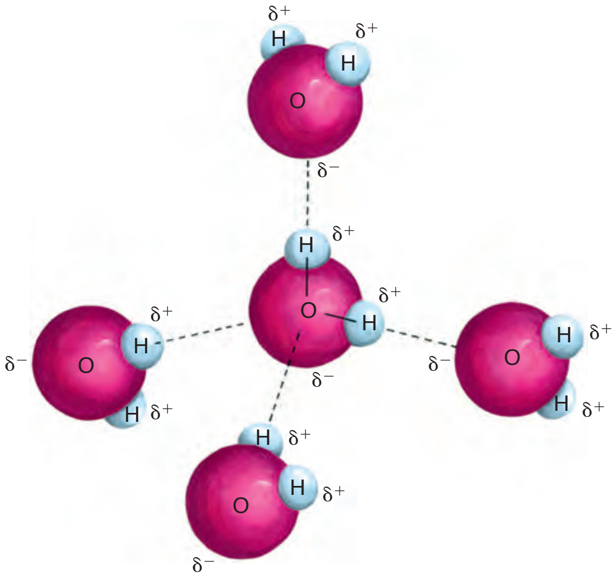
FOR FURTHER THOUGHT

1. Orange juice usually has a pH of around 4. How does this compare with the pH of human blood? Why is it possible for us to drink orange juice without disrupting the pH of our blood?
2. Estrela, age 7, has hot cereal with milk and sugar for breakfast and then walks to school. Explain the relationship between eating and walking; keep in mind that Estrela is breathing.
3. The body is able to store certain nutrients. Name the storage forms, and state an advantage and a disadvantage.
4. Many "vitamin pills" also contain minerals. Which minerals are likely to be found in such dietary supplements? What purposes do these minerals have; that is, what are their functions?
5. Lead is an element that is poisonous to people; it is toxic because it reacts readily with sulfur. Which group of organic molecules is most likely to be damaged by lead and why?
6. Look at the organic molecule depicted in Question Figure 2–A. Begin by naming the major category (one of the four), and then see how specific you can be. Even if you are not sure, give reasons for the possible molecules you can eliminate.



QUESTION FIGURE 2–A: Organic molecule.

7. Look at the inorganic molecules depicted in Question Figure 2–B; they are all the same. What are these five molecules? What kind of bond holds each one together? What kind of bond (shown by dotted lines) holds the five of them together? (The lowercase Greek letter delta [δ+ or δ–] indicates that a partial positive or negative charge is present.) What physical property does this type of bond provide to this substance?



QUESTION FIGURE 2–B: Inorganic molecules.

CHAPTER 6

The Skeletal System

STUDENT OBJECTIVES

- Describe the functions of the skeleton.
- Explain how bones are classified, and give an example of each type.
- Describe how the embryonic skeleton model is replaced by bone.
- Name the nutrients necessary for bone growth, and explain their functions.
- Name the hormones involved in bone growth and maintenance, and explain their functions.
- Explain what is meant by "exercise" for bones, and explain its importance.
- Name all the bones of the human skeleton (be able to point to each on diagrams, skeleton models, or yourself).
- Describe the functions of the skull, vertebral column, rib cage, scapula, and pelvic bone.
- Explain how joints are classified. For each type, give an example, and describe the movement possible.
- Describe the parts of a synovial joint, and explain their functions.

NEW TERMINOLOGY

Appendicular *(AP-en-**DIK**-yoo-lar)*
Articulation *(ar-TIK-yoo-**LAY**-shun)*
Axial *(**AK**-see-uhl)*
Bursa *(**BURR**-sah)*
Diaphysis *(dye-**AFF**-i-sis)*
Epiphyseal disc *(e-**PIFF**-i-SEE-al DISK)*
Epiphysis *(e-**PIFF**-i-sis)*
Fontanel *(FON-tah-**NELL**)*
Haversian system *(ha-**VER**-zhun **SIS**-tem)*
Ligament *(**LIG**-uh-ment)*
Ossification *(AHS-i-fi-**KAY**-shun)*
Osteoblast *(**AHS**-tee-oh-BLAST)*
Osteoclast *(**AHS**-tee-oh-KLAST)*
Paranasal sinus *(PAR-uh-**NAY**-zuhl **SIGH**-nus)*
Periosteum *(PER-ee-**AHS**-tee-um)*
Suture *(**SOO**-cher)*
Symphysis *(**SIM**-fi-sis)*
Synovial fluid *(sin-**OH**-vee-al **FLOO**-id)*

RELATED CLINICAL TERMINOLOGY

Autoimmune disease *(AW-toh-im-**YOON** di-**ZEEZ**)*
Bursitis *(burr-**SIGH**-tiss)*
Fracture *(**FRAK**-chur)*
Herniated disc *(**HER**-nee-ay-ted DISK)*
Kyphosis *(kye-**FOH**-sis)*
Lordosis *(lor-**DOH**-sis)*
Osteoarthritis *(AHS-tee-oh-ar-**THRY**-tiss)*
Osteomyelitis *(AHS-tee-oh-my-uh-**LYE**-tiss)*
Osteoporosis *(AHS-tee-oh-por-**OH**-sis)*
Rheumatoid arthritis *(**ROO**-muh-toyd ar-**THRY**-tiss)*
Rickets *(**RIK**-ets)*
Scoliosis *(SKOH-lee-**OH**-sis)*

*Terms that appear in **bold type** in the chapter text are defined in the glossary, which begins on page 603.*

CHAPTER OUTLINE

Functions of the Skeleton
Types of Bone Tissue
Classification of Bones
Embryonic Growth of Bone
Factors That Affect Bone Growth and Maintenance
The Skeleton
Skull
Vertebral Column
Rib Cage
The Shoulder and Arm
The Hip and Leg
Joints—Articulations
The Classification of Joints
Synovial Joints
Aging and the Skeletal System

BOX 6–1
Fractures and Their Repair

BOX 6–2
Osteoporosis

BOX 6–3
Herniated Disc

BOX 6–4
Abnormalities of the Curves of the Spine

BOX 6–5
Arthritis

Imagine for a moment that people did not have skeletons. What comes to mind? Probably that each of us would be a little heap on the floor, much like a jellyfish out of water. Such an image is accurate and reflects the most obvious function of the skeleton: to support the body. Although it is a framework for the body, the skeleton is not at all like the wooden beams that support a house. Bones are living organs that actively contribute to the maintenance of the internal environment of the body.

The **skeletal system** consists of bones and other structures that make up the joints of the skeleton. The types of tissue present are bone tissue, cartilage, and the fibrous connective tissue that forms the ligaments to connect bone to bone.

FUNCTIONS OF THE SKELETON

1. Provides a framework that supports the body; the muscles that are attached to bones move the skeleton.
2. Protects some internal organs from mechanical injury; the rib cage protects the heart and lungs, for example.
3. Contains and protects the red bone marrow, the primary hemopoietic (blood-forming) tissue.
4. Provides a storage site for excess calcium. Calcium may be removed from bone to maintain a normal blood calcium level, which is essential for blood clotting and proper functioning of muscles and nerves.

TYPES OF BONE TISSUE

Bone was described as a tissue in Chapter 4. Recall that bone cells are called **osteocytes**, and the **matrix** of bone is made of **calcium salts** and collagen. The calcium salts are calcium carbonate ($CaCO_3$) and calcium phosphate ($Ca_3(PO_4)_2$), which give bone the strength required to perform its supportive and protective functions. Bone matrix is non-living, but it changes constantly, with calcium that is taken from bone into the blood replaced by calcium from the diet. In normal circumstances, the amount of calcium that is removed is replaced by an equal amount of calcium deposited. This is the function of osteocytes. The primary cilia of osteocytes detect changes in the calcium content of the tissue fluid that surrounds them, which enables the cells to regulate the amount of calcium that is deposited in, or removed from, the bone matrix.

In bone as an organ, two types of bone tissue are present (Fig. 6–1). **Compact bone** looks solid but is very precisely structured. Compact bone is made of **osteons** or **haversian systems**, microscopic cylinders of bone matrix with osteocytes in concentric rings around central **haversian canals**. You can see that the osteocytes look somewhat like spiders, with the “legs” of adjacent spiders in contact. These “legs” are cytoplasmic extensions of osteocytes through microscopic **canaliculi**, or “little canals” in the matrix. In the haversian canals are blood vessels; the innermost osteocytes are in contact with these blood vessels and receive nutrients and oxygen. These useful materials are then passed to the osteocytes in the outer rings.

The second type of bone tissue is **spongy bone**, which does look rather like a sponge with its visible holes or cavities. Osteocytes, matrix, and blood vessels are present but are not arranged in haversian systems. The cavities in spongy bone often contain **red bone marrow**, which produces red blood cells, platelets, and the five kinds of white blood cells.

CLASSIFICATION OF BONES

1. **Long bones**—the bones of the arms, legs, hands, and feet (but not the wrists and ankles). The shaft of a long bone is the **diaphysis**, and the ends are called **epiphyses** (see Fig. 6–1). The diaphysis is made of compact bone and is hollow, forming a canal within the shaft. This **marrow canal** (or medullary cavity) contains **yellow bone marrow**, which is mostly adipose tissue. The epiphyses are made of spongy bone covered with a thin layer of compact bone. Although red bone marrow is present in the epiphyses of children’s bones, it is largely replaced by yellow bone marrow in adult bones.
2. **Short bones**—the bones of the wrists and ankles.
3. **Flat bones**—the ribs, shoulder blades, hipbones, and cranial bones.
4. **Irregular bones**—the vertebrae and facial bones.

Short, flat, and irregular bones are all made of spongy bone covered with a thin layer of compact bone. Red bone marrow is found within the spongy bone.

The joint surfaces of bones are covered with **articular cartilage**, which provides a smooth surface. Covering the rest of the bone is the **periosteum**, a fibrous connective tissue membrane whose collagen fibers merge with those of the tendons and **ligaments** that are attached to the bone. The periosteum anchors these structures and contains both the blood vessels that enter the bone itself and osteoblasts that will become active if the bone is damaged.

EMBRYONIC GROWTH OF BONE

During embryonic development, the skeleton is first made of cartilage and fibrous connective tissue, which are gradually replaced by bone. Bone matrix is produced by cells

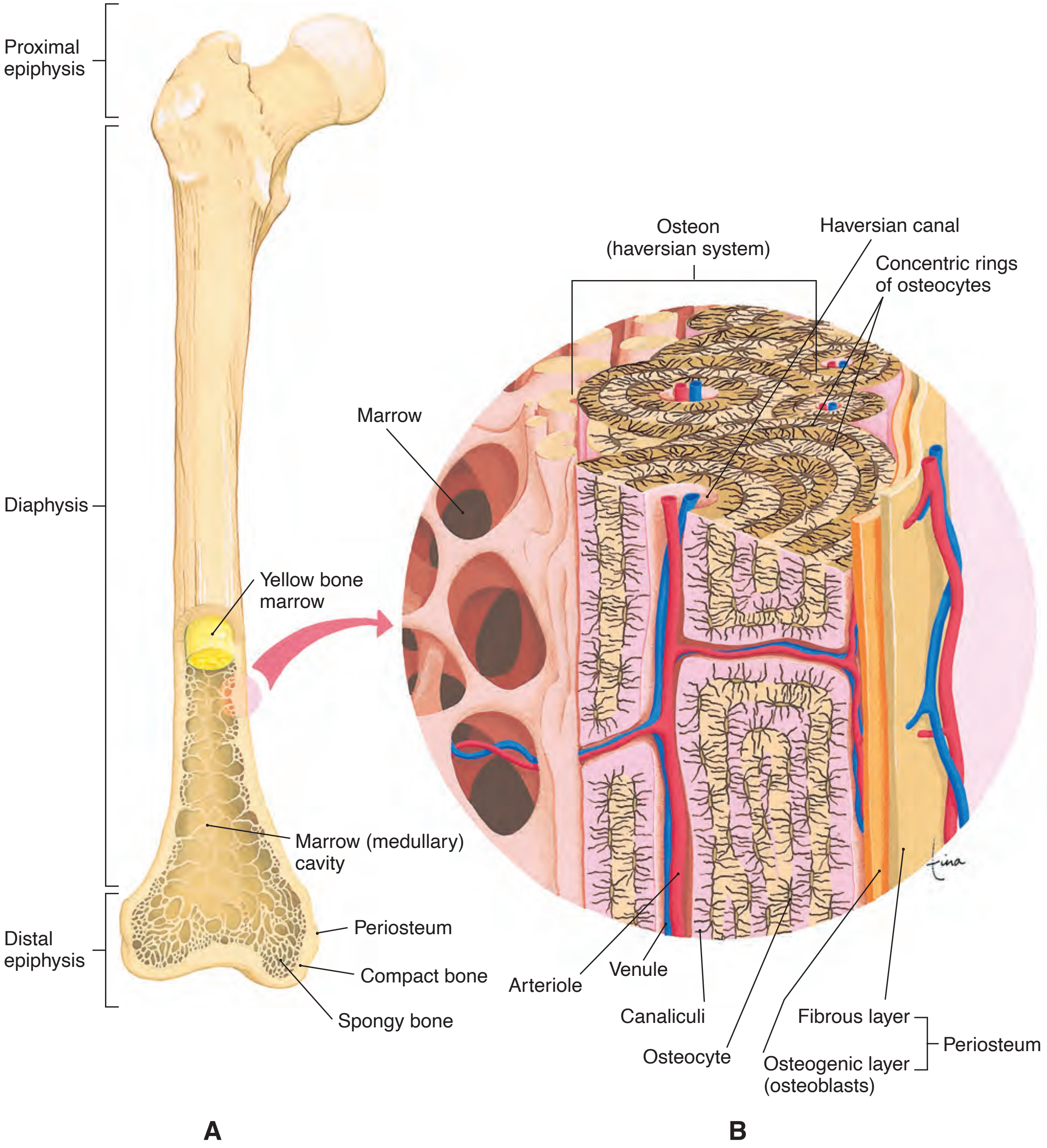


Figure 6–1 Bone tissue. (**A**) Femur with distal end cut in longitudinal section. (**B**) Compact bone showing haversian systems (osteons).

QUESTION: What is the purpose of the blood vessels in bone tissue?

called **osteoblasts** (a *blast* cell is a "growing" or "producing" cell, and *osteo* means "bone"). In the embryonic model of the skeleton, osteoblasts differentiate from the fibroblasts that are present. The production of bone matrix, called **ossification**, begins in a **center of ossification** in each bone.

The cranial and facial bones are first made of fibrous connective tissue. In the third month of fetal development, fibroblasts (spindle-shaped connective tissue cells) become more specialized and differentiate into osteoblasts, which produce bone matrix. From each center of ossification, bone growth radiates outward as calcium salts are deposited in the collagen of the model of the bone. This process is not complete at birth; a baby has areas of fibrous connective tissue remaining between the bones of the skull. These are called **fontanels** (Fig. 6–2), which permit compression of the baby's head during

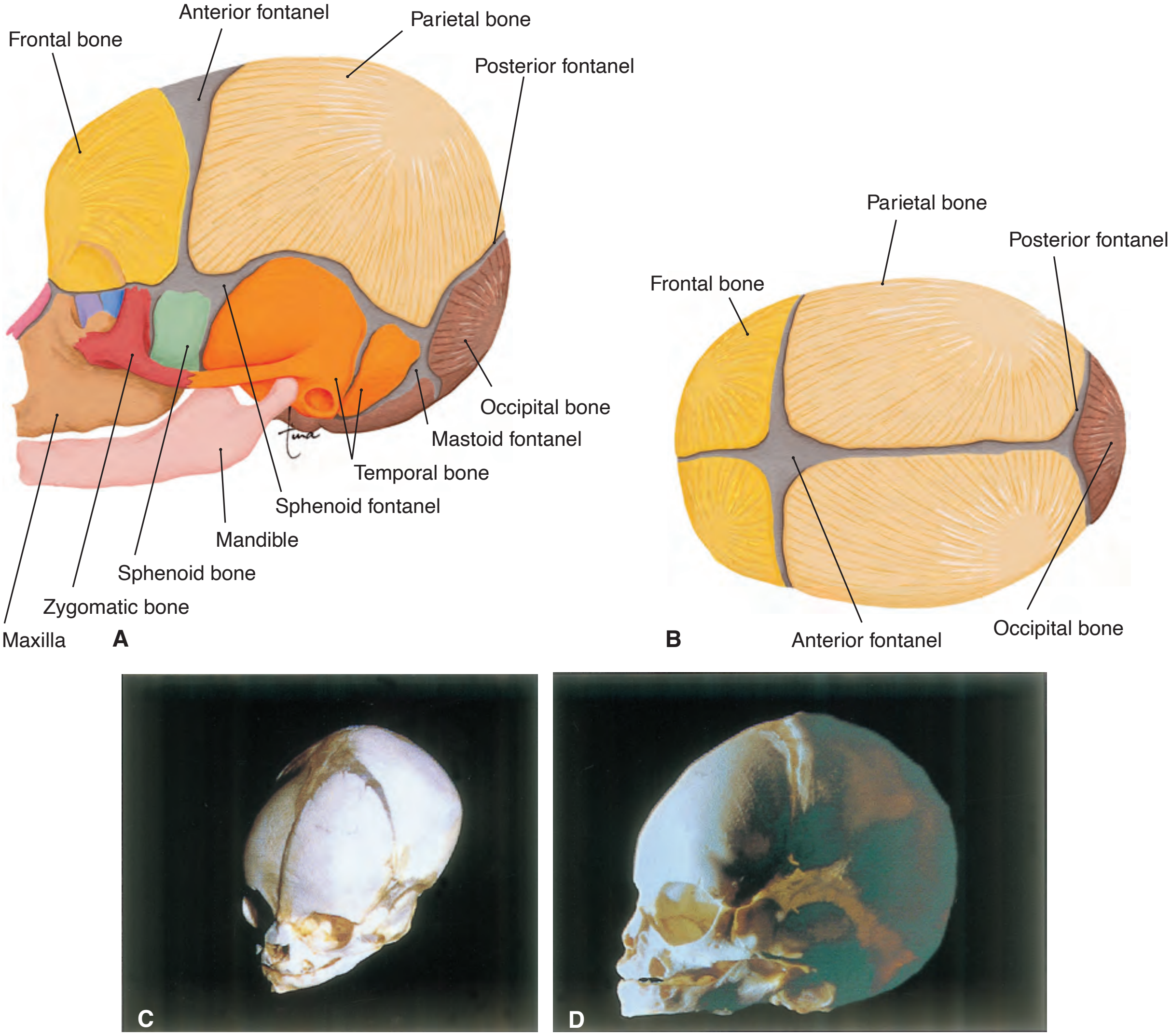


Figure 6–2 Infant skull with fontanels. (**A**) Lateral view of left side. (**B**) Superior view. (**C**) Fetal skull in anterior superior view. (**D**) Fetal skull in left lateral view. Try to name the bones; use part A as a guide. The fontanels are translucent connective tissue. (C and D photographs by Dan Kaufman.)

QUESTION: What is the difference between the frontal bone of the infant skull and that of the adult skull?

birth without breaking the still thin cranial bones. The fontanels also permit the growth of the brain after birth. You may have heard fontanels referred to as "soft spots," and indeed they are. A baby's skull is quite fragile and must be protected from trauma. By the age of 2 years, all the fontanels have become ossified, and the skull becomes a more effective protective covering for the brain.

The rest of the embryonic skeleton is first made of cartilage, and ossification begins in the third month of gestation in the long bones. Osteoblasts produce bone matrix in the center of the diaphyses of the long bones and in the center of short, flat, and irregular bones. Bone matrix gradually replaces the original cartilage (Fig. 6–3).

The long bones also develop centers of ossification in their epiphyses. At birth, ossification is not yet complete and continues throughout childhood. In long bones, growth occurs in the **epiphyseal discs** at the junction of the diaphysis with each epiphysis. An epiphyseal disc is still cartilage, and the bone grows in length as more cartilage is produced on the epiphysis side (see Fig. 6–3). On the diaphysis side, osteoblasts produce bone matrix to replace the cartilage. Some osteoblasts become surrounded by bone and settle down to become maintenance cells, the osteocytes. As long as cartilage is produced, some osteoblasts will follow and replace the cartilage. Between the ages of 16 and 25 years (influenced by estrogen or testosterone), all of the cartilage matrix of the epiphyseal discs is replaced by bone matrix. This is called closure of the epiphyseal discs (or we say the discs are closed), and the bone lengthening process stops.

Also in bones, and shown in Fig. 6–3, are the specialized cells called **osteoclasts** (a *clast* cell is a "destroying" cell), which are large cells with several nuclei and a "ruffled skirt" appearance. An osteoclast secretes acid and enzymes to dissolve and digest a microscopic bit of bone matrix, and then absorbs the minerals and amino acids; this process is called **resorption**. Osteoclasts are very active in embryonic long bones, and they reabsorb bone matrix in the center of the diaphysis to form the **marrow canal**. Blood vessels grow into the marrow canals of embryonic long bones, and red bone marrow is established. After birth, the red bone marrow is replaced by yellow bone marrow. Red bone marrow remains in the spongy bone of short, flat, and irregular bones.

Bone tissue and bones as organs are never really "finished." Throughout life, bone matrix undergoes a process called **remodeling**. Calcium is removed by osteoclasts to raise the blood calcium level, or calcium salts are made and deposited by osteoblasts to lower the blood calcium level. These cells also respond to environmental factors such as the body's bearing extra weight. For the functions of osteoclasts and osteoblasts following bone injury, see Box 6–1: Fractures and Their Repair.

FACTORS THAT AFFECT BONE GROWTH AND MAINTENANCE

1. Heredity—each person has a genetic potential for height, that is, a maximum height, with genes inherited from both parents. Many genes are involved, and their interactions are not well understood. Some of these genes are probably those for the enzymes involved in cartilage and bone production because this is how bones grow.
2. Nutrition—nutrients are the raw materials of which bones are made. Calcium, phosphorus, and protein become part of the bone matrix itself. Vitamin D is needed for the efficient absorption of calcium and phosphorus by the small intestine. Vitamin D deficiency in children causes **rickets**; bones are soft and weight-bearing bones often bend. Vitamins A and C do not become part of bone but are necessary for the process of bone matrix formation (ossification or calcification). Without these and other nutrients, bones cannot grow properly. Children who are malnourished grow very slowly and may not reach their genetic potential for height.
3. Hormones—endocrine glands produce hormones that stimulate specific effects in certain cells. Several hormones make important contributions to bone growth and maintenance. These include growth hormone, thyroxine, parathyroid hormone, and insulin, which help regulate cell division, protein synthesis, calcium metabolism, and energy production. The sex hormones estrogen or testosterone help bring about the cessation of bone growth. The hormones and their specific functions are listed in Table 6–1.
4. Chemical communication from other tissues—as mentioned in Chapter 4, adipose tissue produces leptin that stimulates osteoblasts to produce bone matrix. The body's energy-storage tissue communicates with the body's weight-bearing tissue. Bone tissue communicates in return. Osteoblasts produce a protein called **osteocalcin**, which decreases fat storage by adipose tissue and increases insulin production by the pancreas. Both of these responses are believed to help the body maintain a normal weight.

   The small intestine also communicates with bone tissue. Cells in the small intestine produce serotonin

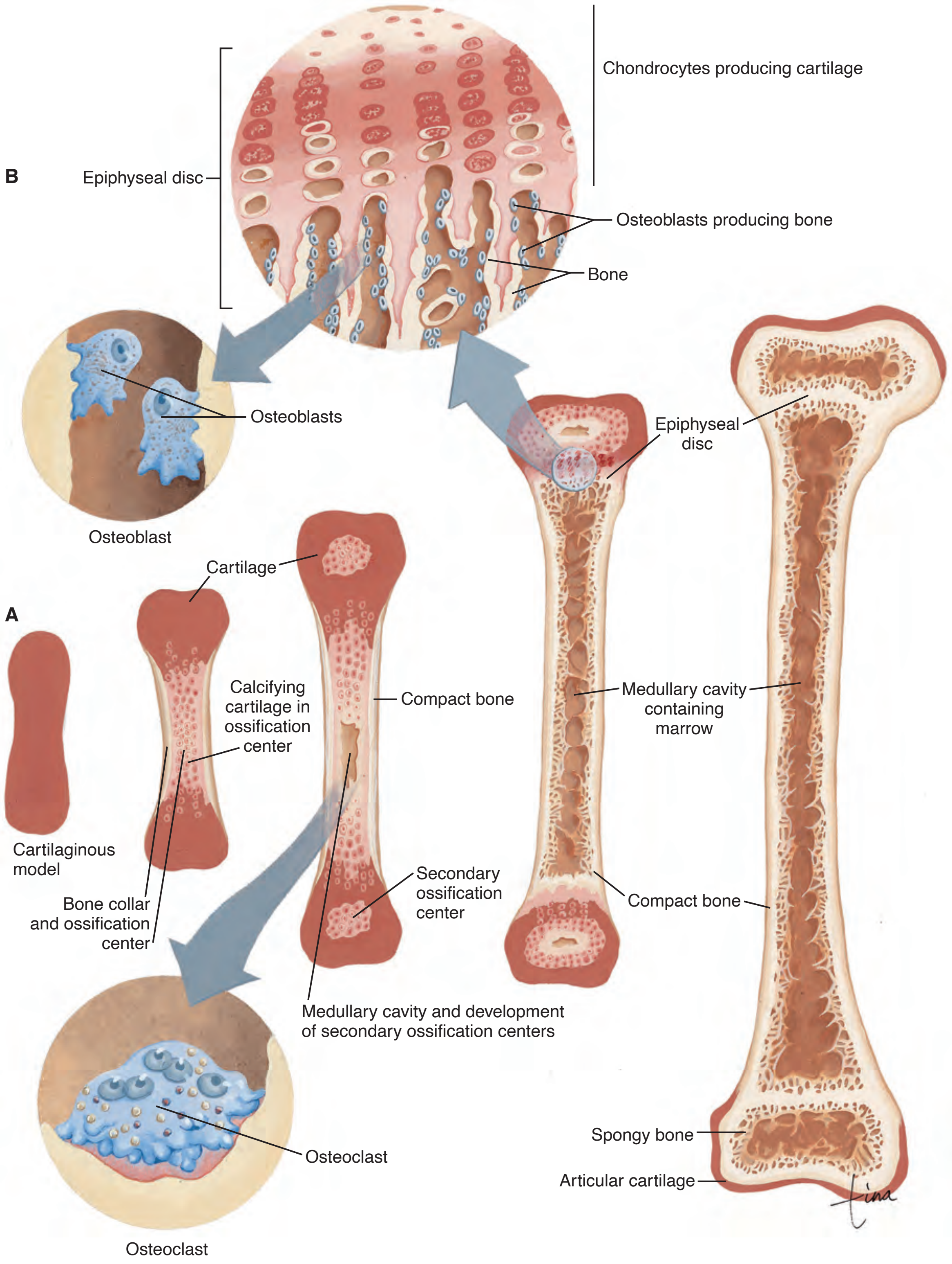

B
Epiphyseal disc
Chondrocytes producing cartilage
Osteoblasts producing bone
Bone
Osteoblasts
Osteoblast
Epiphyseal disc
A
Cartilage
Calcifying cartilage in ossification center
Compact bone
Cartilaginous model
Bone collar and ossification center
Secondary ossification center
Medullary cavity containing marrow
Compact bone
Medullary cavity and development of secondary ossification centers
Osteoclast
Osteoclast
Spongy bone
Articular cartilage
Tina

Figure 6–3 The ossification process in a long bone. (**A**) Progression of ossification from the cartilage model of the embryo to the bone of a young adult. (**B**) Microscopic view of an epiphyseal disc showing cartilage production and bone replacement.

QUESTION: The epiphyseal discs of the bone on the far right are closed. What does that mean?

Box 6–1 | FRACTURES AND THEIR REPAIR

A **fracture** means that a bone has been broken. There are different types of fractures classified as to extent of damage (Box Fig. 6–A):

Simple (closed)—the broken parts are still in normal anatomic position; surrounding tissue damage is minimal (skin is not pierced).

Compound (open)—the broken end of a bone has been moved, and it pierces the skin; there may be extensive damage to surrounding blood vessels, nerves, and muscles. The break in the skin permits the entry of bacteria, which may cause **osteomyelitis**, an infection of bone.

Greenstick—the bone splits longitudinally. The bones of children contain more collagen than do adult bones and tend to splinter rather than break completely.

Comminuted—two or more intersecting breaks create several bone fragments.

Impacted—the broken ends of a bone are forced into one another; many bone fragments may be created.

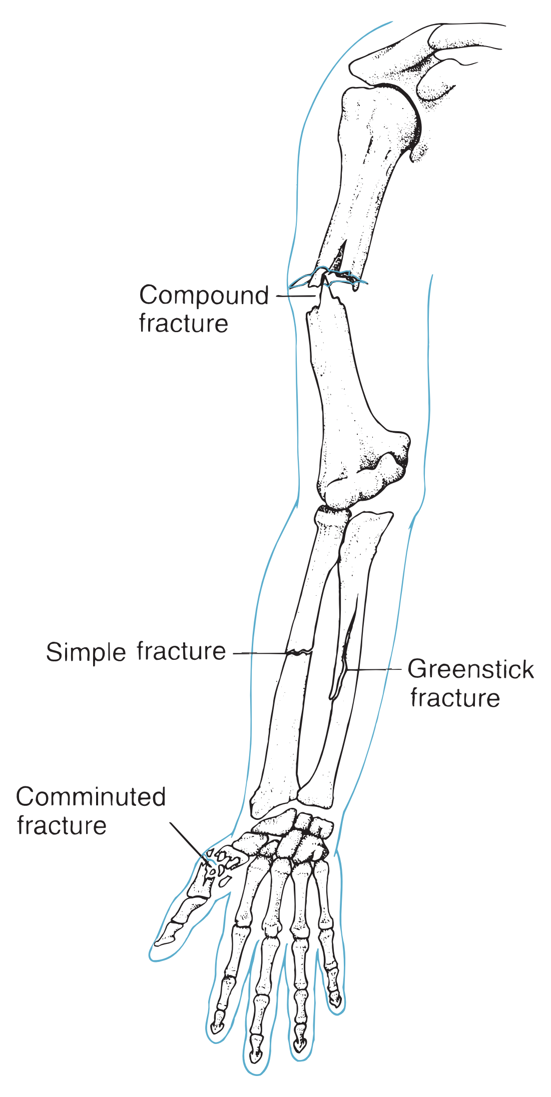
Pathologic (spontaneous)—a bone breaks without apparent trauma; may accompany bone disorders such as osteoporosis.

THE REPAIR PROCESS

Even a simple fracture involves significant bone damage that must be repaired if the bone is to resume its normal function. Fragments of dead or damaged bone must first be removed. This is accomplished by osteoclasts, which dissolve and reabsorb the calcium salts of bone matrix. Imagine a building that has just collapsed; the rubble must be removed before reconstruction can take place. This is what the osteoclasts do. Then, new bone must be produced. The inner layer of the periosteum contains osteoblasts that are activated when bone is damaged. The osteoblasts produce bone matrix to knit the broken ends of the bone together.

Because most bone has a good blood supply, the repair process is usually relatively rapid, and a simple fracture often heals within 6 weeks. Some parts of bones, however, have a poor blood supply, and repair of fractures takes longer. These areas are the neck of the femur (the site of a "fractured hip") and the lower third of the tibia.

Other factors that influence repair include the age of the person, general state of health, and nutrition. The elderly and those in poor health often have slow healing of fractures. A diet with sufficient calcium, phosphorus, vitamin D, and protein is also important. If any of these nutrients is lacking, bone repair will be a slower process.



Box Figure 6–A Types of fractures. Several types of fractures are depicted in the right arm.

Table 6–1 | HORMONES INVOLVED IN BONE GROWTH AND MAINTENANCE

HORMONE (GLAND)	FUNCTIONS
Growth hormone (anterior pituitary gland)	■ Increases the rate of mitosis of chondrocytes and osteoblasts ■ Increases the rate of protein synthesis (collagen, cartilage matrix, and enzymes for cartilage and bone formation)
Thyroxine (thyroid gland)	■ Increases the rate of protein synthesis ■ Increases energy production from all food types
Insulin (pancreas)	■ Increases energy production from glucose
Parathyroid hormone (parathyroid glands)	■ Increases the reabsorption of calcium from bones to the blood (raises blood calcium level) ■ Increases the absorption of calcium by the small intestine and kidneys (to the blood)
Calcitonin (thyroid gland)	■ Decreases the reabsorption of calcium from bones (lowers blood calcium level)
Estrogen (ovaries) or testosterone (testes)	■ Promotes closure of the epiphyses of long bones (growth stops) ■ Helps retain calcium in bones to maintain a strong bone matrix

(gut serotonin); you may have heard of serotonin as a CNS neurotransmitter that affects mood (brain serotonin). Gut serotonin is much more abundant than brain serotonin, but gut serotonin does not affect the brain. It does, however, inhibit osteoblasts from producing bone matrix, the opposite of the effect of leptin. We have much more to learn, but for now we can say that bone tissue is also influenced by the organ most responsible for absorption of nutrients, the small intestine.

5. Exercise or “stress”—for bones, exercise means bearing weight, which is just what bones are specialized to do. Without this stress (which is normal and necessary), bones will lose calcium faster than it is replaced. Exercise need not be strenuous; it can be as simple as the walking involved in everyday activities. Strenuous exercise that includes bearing more than the body’s own weight will remodel bones; they will become thicker and stronger as more matrix is deposited (given sufficient calcium and phosphorus in the diet). Bones that do not get even minimal exercise, such as those of patients confined to bed, will be remodeled as well, but they will lose matrix and become thinner and more fragile. This condition is discussed further in Box 6–2: Osteoporosis.

THE SKELETON

The human skeleton has two divisions: the **axial skeleton**, which forms the axis of the body, and the **appendicular skeleton**, which supports the appendages or limbs. The axial skeleton consists of the skull, vertebral column, and rib cage. The bones of the arms and legs and the shoulder and pelvic girdles make up the appendicular skeleton. Many bones are connected to other bones across joints by ligaments, which are strong cords or sheets of fibrous connective tissue. The importance of ligaments becomes readily apparent when a joint is sprained. A sprain is the stretching or even tearing of the ligaments of a joint, and though the bones are not broken, the joint is weak and unsteady. We do not often think of our ligaments, but they are necessary to keep our bones in the proper positions to keep us upright or to bear weight.

The body has 206 bones in total. The complete skeleton is shown in Fig. 6–4.

SKULL

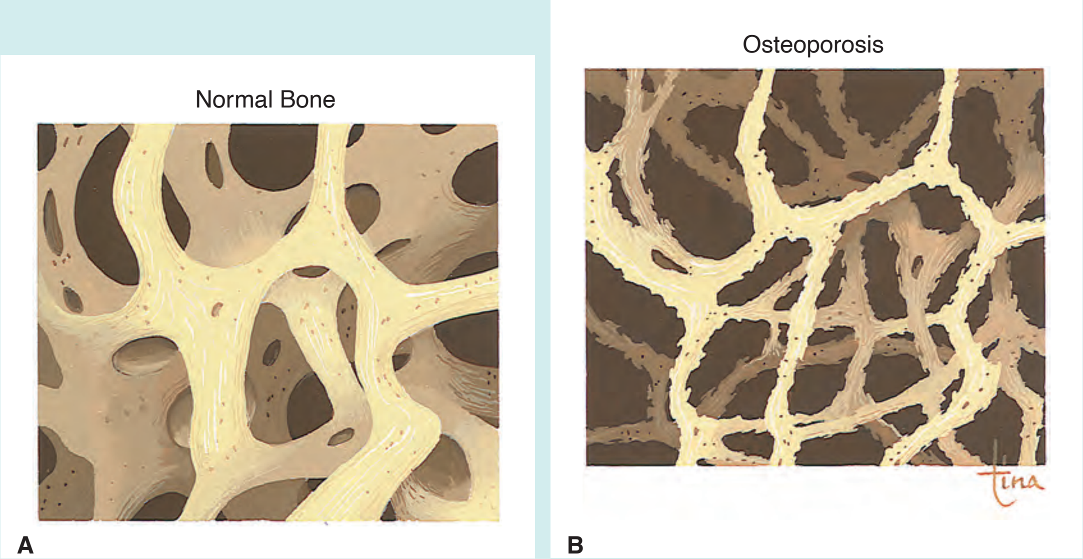
The **skull** consists of 8 cranial bones and 14 facial bones. Also in the head are three small bones in each middle ear cavity and the hyoid bone that supports the base of the tongue. The **cranial bones** form the braincase (lined with

Box 6–2 | OSTEOPOROSIS

Bone is an active tissue; calcium is constantly being removed to maintain normal blood calcium levels. Usually, however, calcium is replaced in bones at a rate equal to its removal, and the bone matrix remains strong.

Osteoporosis is characterized by excessive loss of calcium from bones without sufficient replacement (Box Fig. 6–B). Research has suggested that a certain gene for bone buildup in youth is an important factor; less buildup would mean earlier bone thinning. Contributing environmental factors include smoking, insufficient dietary intake of calcium, inactivity, and lack of the sex hormones. Osteoporosis is most common among elderly women because estrogen secretion decreases sharply at menopause (in older men, testosterone is still secreted in significant amounts). Factors such as bed rest or inability to get even minimal exercise will make calcium loss even more rapid.

As bones lose calcium and become thin and brittle, fractures are much more likely to occur. Among elderly women, a fractured hip (the neck of the femur) may be a consequence of this degenerative bone disorder. Such a serious injury is not inevitable, however, and neither is the thinning of the vertebrae that bows the spines of some elderly people. After menopause, women may wish to have a bone density test to determine the strength of their bone matrix. Several medications are available that diminish the rate of bone loss, and some claim to increase matrix production. A diet high in calcium and vitamin D is essential for both men and women, as is moderate exercise. Young women and teenagers should make sure they get adequate dietary calcium to form strong bone matrix because this will delay the serious effects of osteoporosis later in life.



Box Figure 6–B (A) Normal spongy bone, as in the body of a vertebra. (**B**) Spongy bone thinned by osteoporosis.

the meninges) that encloses and protects the brain, eyes, and ears. The names of some of these bones will be familiar to you; they are the same as the terminology used (see Chapter 1) to describe areas of the head. These are the frontal bone, parietal bones (two), temporal bones (two), and occipital bone. The sphenoid bone and ethmoid bone are part of the floor of the braincase and the orbits (sockets) for the eyes. The **frontal bone** forms the forehead and the anterior part of the top of the skull. *Parietal* means "wall," and the two large **parietal bones** form the posterior top and

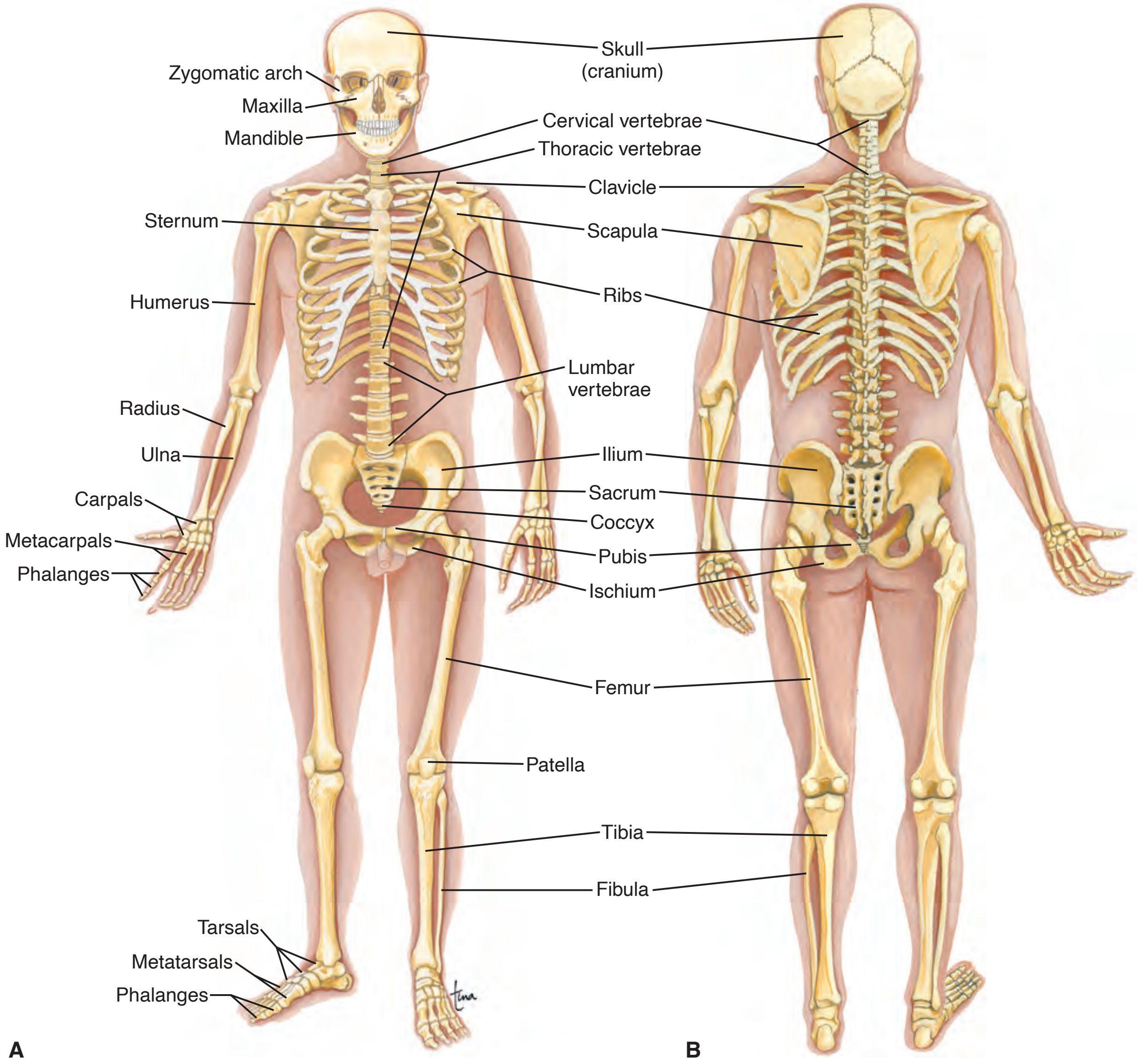


Figure 6–4 Skeleton. (**A**) Anterior view. (**B**) Posterior view.

QUESTION: Which of the bones shown here are classified as irregular bones?

much of the side walls of the skull. Each **temporal bone** on the side of the skull contains an external auditory meatus (ear canal), a middle ear cavity, and an inner ear labyrinth. The **occipital bone** forms the lower, posterior part of the braincase. Its foramen magnum is a large opening for the spinal cord, and the two condyles (rounded projections) on either side articulate with the atlas, the first cervical vertebra. The **sphenoid bone** is said to be shaped like a bat, and the greater wing is visible on the side of the skull between the frontal and temporal bones. The body of the bat has a depression called the sella turcica, which encloses the pituitary gland. The **ethmoid bone** has a vertical projection called the crista galli ("rooster's comb") that anchors the cranial meninges. The rest of the ethmoid bone forms the roof and upper walls of the nasal cavities, and its perpendicular plate forms the upper part of the nasal septum.

All of the joints between cranial bones are immovable joints called **sutures**. It may seem strange to refer to a joint without movement, but the term *joint* (or **articulation**) is used for any junction of two bones. (The classification of joints will be covered later in this chapter.) In a suture, the serrated, or sawtooth, edges of adjacent bones fit into each other. These interlocking projections prevent sliding or shifting of the bones if the skull is subjected to a blow or pressure. In Fig. 6–5 you can see the coronal suture between the frontal and parietal bones, the squamosal suture between the parietal and temporal bones, and the lambdoidal suture between the occipital and parietal bones. Not visible is the sagittal suture, where the two parietal bones articulate along the midline of the top of the skull. All the bones of the skull, as well as the large sutures, are shown in Figs. 6–5 through 6–8. Their anatomically important parts are described in Table 6–2.

Of the 14 **facial bones**, only the **mandible** (lower jaw) is movable; it forms a **condyloid joint** with each temporal bone. The other joints between facial bones are all sutures. The **maxillae** are the two upper jawbones, which also form the anterior portion of the hard palate (roof of the mouth). Sockets for the roots of the teeth are found in the maxillae and the mandible. The two **nasal bones** form the bridge of the nose where they articulate with the frontal bone (the rest of the nose is supported by cartilage). There is a **lacrimal bone** at the medial side of each orbit; the lacrimal canal contains the lacrimal sac, a passageway for tears. Each of the two **zygomatic bones** forms the point of a cheek and articulates with the maxilla, frontal bone, and temporal bone. The two **palatine bones** are the posterior portion of the hard palate. The plow-shaped **vomer** forms the lower part of the nasal septum; it articulates with the perpendicular plate of the ethmoid bone. On either side of the vomer are the **conchae**, six scroll-like bones that curl downward from the sides of the nasal cavities; they help increase the surface area of the nasal mucosa. These facial bones are included in Table 6–2.

Paranasal sinuses are air cavities located in the maxillae and frontal, sphenoid, and ethmoid bones (Fig. 6–9). As the name *paranasal* suggests, they open into the nasal cavities and are lined with **ciliated epithelium** continuous with the mucosa of the nasal cavities. We are aware of our sinuses only when they become “stuffed up,” which means that the mucus they produce cannot drain into the nasal cavities. This may happen during upper respiratory infections such as colds, or with allergies such as hay fever. These sinuses, however, do have functions: They make the skull lighter in weight because air is lighter than bone, and they provide resonance for the voice, meaning more air to vibrate and thus deepen the pitch of the voice.

The **mastoid sinuses** are air cavities in the mastoid process of each temporal bone; they open into the middle ear. Before the availability of antibiotics, middle ear infections often caused mastoiditis, infection of these sinuses.

Within each middle ear cavity are three **auditory bones**: the malleus, incus, and stapes. As part of the hearing process (discussed in Chapter 9), these bones transmit vibrations from the eardrum to the receptors in the inner ear (see Fig. 9–9 in Chapter 9).

VERTEBRAL COLUMN

The **vertebral column** (spinal column or backbone) is made of individual bones called **vertebrae**. The names of vertebrae indicate their location along the length of the spinal column. There are 7 cervical vertebrae, 12 thoracic, 5 lumbar, 5 sacral fused into 1 sacrum, and 4 to 5 small coccygeal vertebrae fused into 1 coccyx (Fig. 6–10).

The seven **cervical vertebrae** are those within the neck. The first vertebra is called the **atlas**, which articulates with the occipital bone to support the skull and forms a **pivot joint** with the odontoid process of the **axis**, the second cervical vertebra. This pivot joint allows us to turn our heads from side to side. The remaining five cervical vertebrae do not have individual names.

The **thoracic vertebrae** articulate (form joints) with the ribs on the posterior side of the trunk. The **lumbar vertebrae**, the largest and strongest bones of the spine, are found in the small of the back. The **sacrum** permits the articulation of the two hipbones: the **sacroiliac joints**. The **coccyx** is the remnant of tail vertebrae, and some muscles of the perineum (pelvic floor) are anchored to it.

All of the vertebrae articulate with one another in sequence, connected by ligaments, to form a flexible backbone that supports the trunk and head. They also form the **vertebral canal**, a continuous tunnel (lined with the meninges) that contains the spinal cord and protects it from mechanical injury. The spinous and transverse processes are projections for the attachment of the muscles that bend the vertebral column. The facets of some vertebrae are small flat surfaces for articulation with other bones, such as the ribs with the facets of the thoracic vertebrae.

The supporting part of a vertebra is its body; the bodies of adjacent vertebrae are separated by **discs** of fibrous cartilage. These discs cushion and absorb shock and permit some movement between vertebrae (**symphysis joints**).

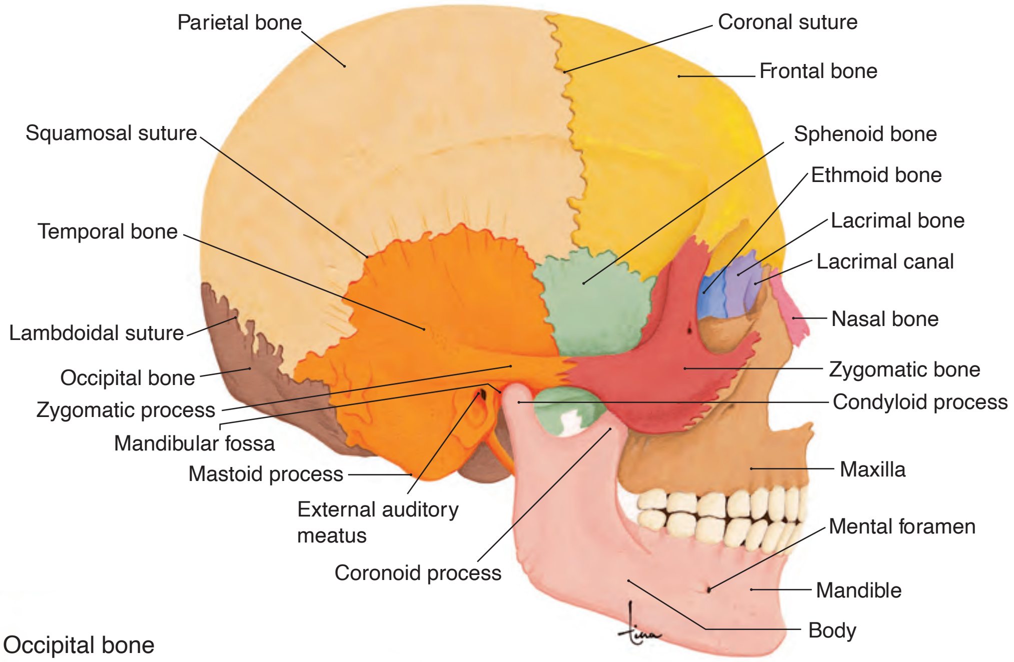


Figure 6–5 Skull. Lateral view of right side.

- 🟫 Occipital bone
- 🟨 Frontal bone
- 🟥 Zygomatic bone
- 🟫 Maxillary bone
- ⬜ Mandible
- 🟨 Parietal bone
- 🟧 Temporal bone
- 🟩 Sphenoid bone
- 🟦 Ethmoid bone
- 🟪 Lacrimal bone
- 🟥 Nasal bone
- 🟦 Inferior nasal concha
- 🟧 Vomer
- ⬜ Palatine bone

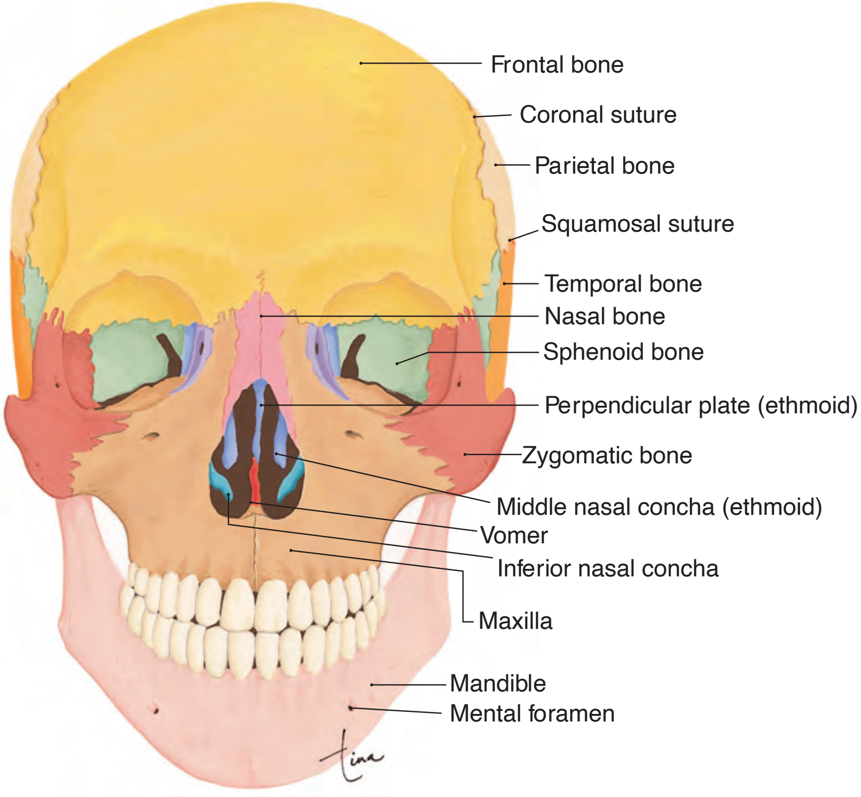
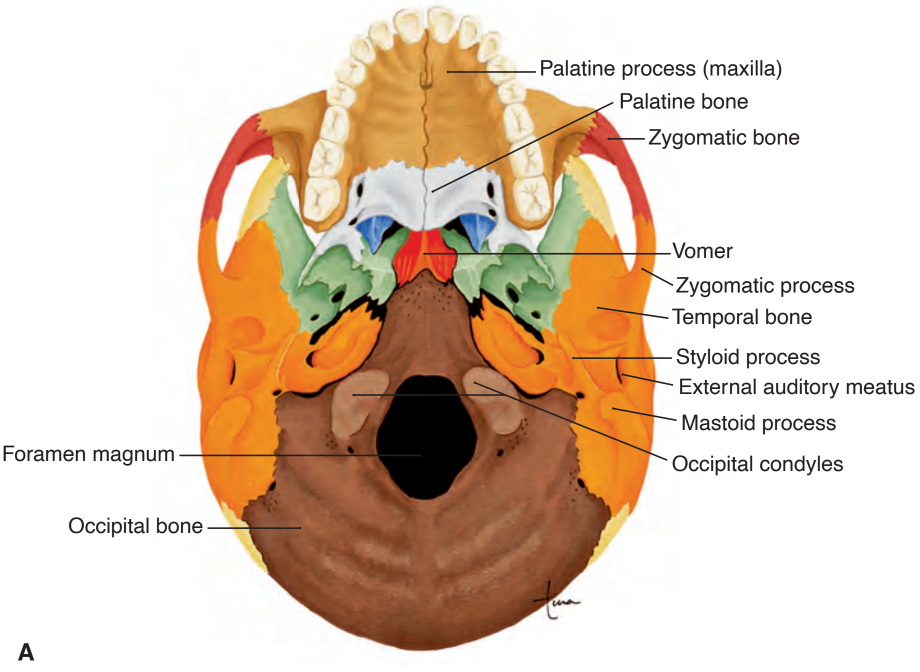


Figure 6–6 Skull. Anterior view.

QUESTION: What might be the purpose of the openings at the back of the eye sockets?



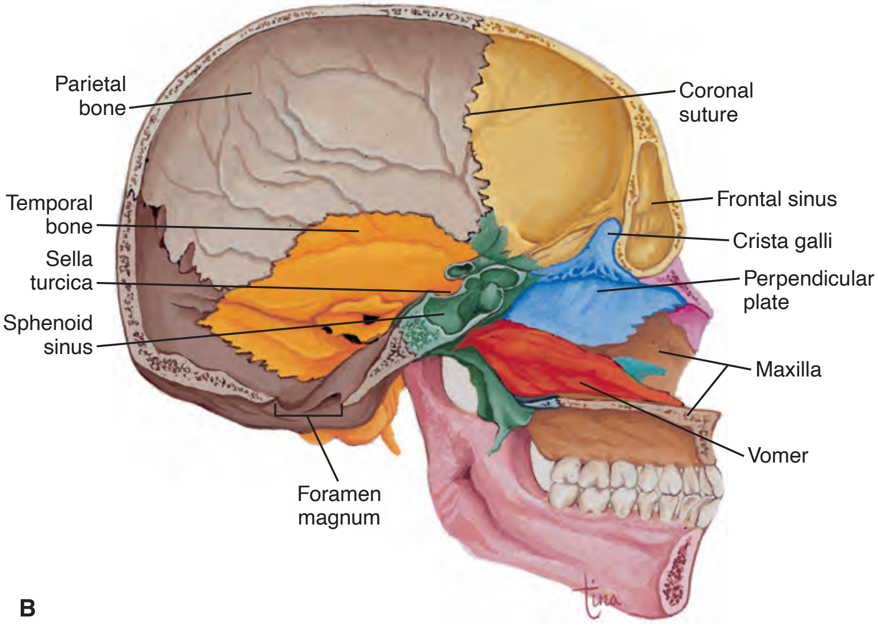


Figure 6–7 Skull. (**A**) Inferior view with mandible removed. (**B**) Midsagittal section showing interior of left side.

QUESTION: What is the purpose of the foramen magnum?

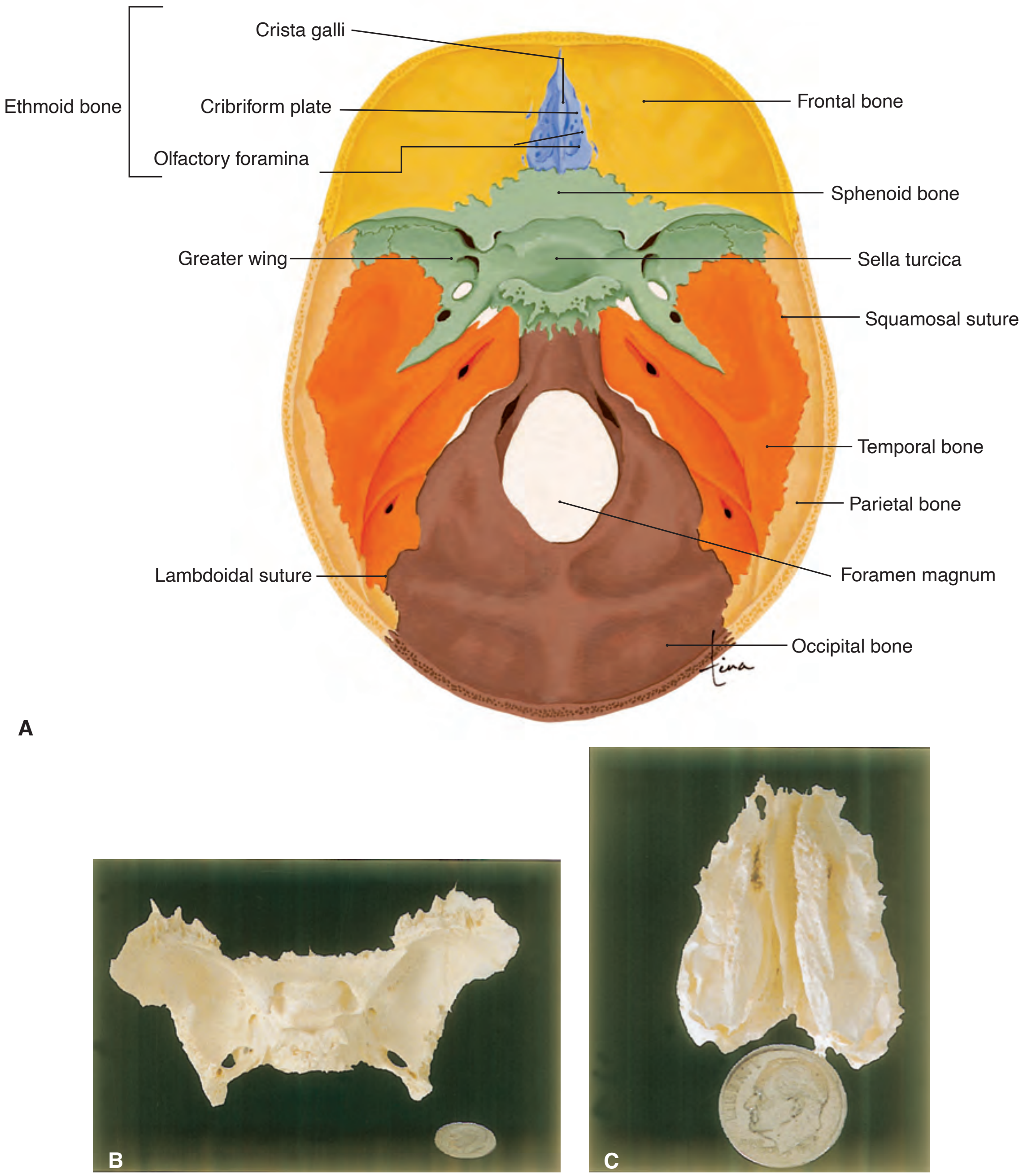


Figure 6–8 (**A**) Skull. Superior view with the top of cranium removed. (**B**) Sphenoid bone in superior view. (**C**) Ethmoid bone in superior view. (B and C photographs by Dan Kaufman.)

QUESTION: What are the olfactory foramina of the ethmoid bone for?

Table 6–2 | BONES OF THE SKULL—IMPORTANT PARTS

TERMINOLOGY OF BONE MARKINGS		
Foramen—a hole or opening	Meatus—a tunnel-like cavity	Condyle—a rounded projection
Fossa—a depression	Process—a projection	Plate—a flat projection
Crest—a ridge or edge	Facet—a flat projection	Tubercle—a round projection

BONE	PART	DESCRIPTION
Frontal	Frontal sinus Coronal suture	■ Air cavity that opens into nasal cavity ■ Joint between frontal and parietal bones
Parietal (2)	Sagittal suture	■ Joint between the 2 parietal bones
Temporal (2)	Squamosal suture External auditory meatus Mastoid process Mastoid sinus Mandibular fossa Zygomatic process	■ Joint between temporal and parietal bone ■ The tunnel-like ear canal ■ Oval projection behind the ear canal ■ Air cavity that opens into middle ear ■ Oval depression anterior to the ear canal; articulates with mandible ■ Anterior projection that articulates with the zygomatic bone
Occipital	Foramen magnum Condyles Lambdoidal suture	■ Large opening for the spinal cord ■ Oval projections on either side of the foramen magnum; articulate with the atlas ■ Joint between occipital and parietal bones
Sphenoid	Greater wing Sella turcica Sphenoid sinus	■ Flat, lateral portion between the frontal and temporal bones ■ Central depression that encloses the pituitary gland ■ Air cavity that opens into the nasal cavity
Ethmoid	Ethmoid sinus Crista galli Cribriform plate and olfactory foramina Perpendicular plate Conchae (4 are part of ethmoid; 2 inferior are separate bones)	■ Air cavity that opens into nasal cavity ■ Superior projection for attachment of meninges ■ On either side of base of crista galli; olfactory nerves pass through foramina ■ Upper part of nasal septum ■ Shelf-like projections into nasal cavities that increase surface area of nasal mucosa
Mandible	Body Condyles Sockets	■ U-shaped portion with lower teeth ■ Oval projections that articulate with the temporal bones ■ Conical depressions that hold roots of lower teeth

Continued

Table 6–2 | BONES OF THE SKULL—IMPORTANT PARTS—cont'd

BONE	PART	DESCRIPTION
Maxilla (2)	Maxillary sinus Palatine process Sockets	■ Air cavity that opens into nasal cavity ■ Projection that forms anterior part of hard palate ■ Conical depressions that hold roots of upper teeth
Nasal (2)	—	■ Form the bridge of the nose
Lacrimal (2)	Lacrimal canal	■ Opening for nasolacrimal duct to take tears to nasal cavity
Zygomatic (2)	—	■ Form point of cheek; articulate with frontal, temporal, and maxillae
Palatine (2)	—	■ Form the posterior part of hard palate
Vomer	—	■ Lower part of nasal septum

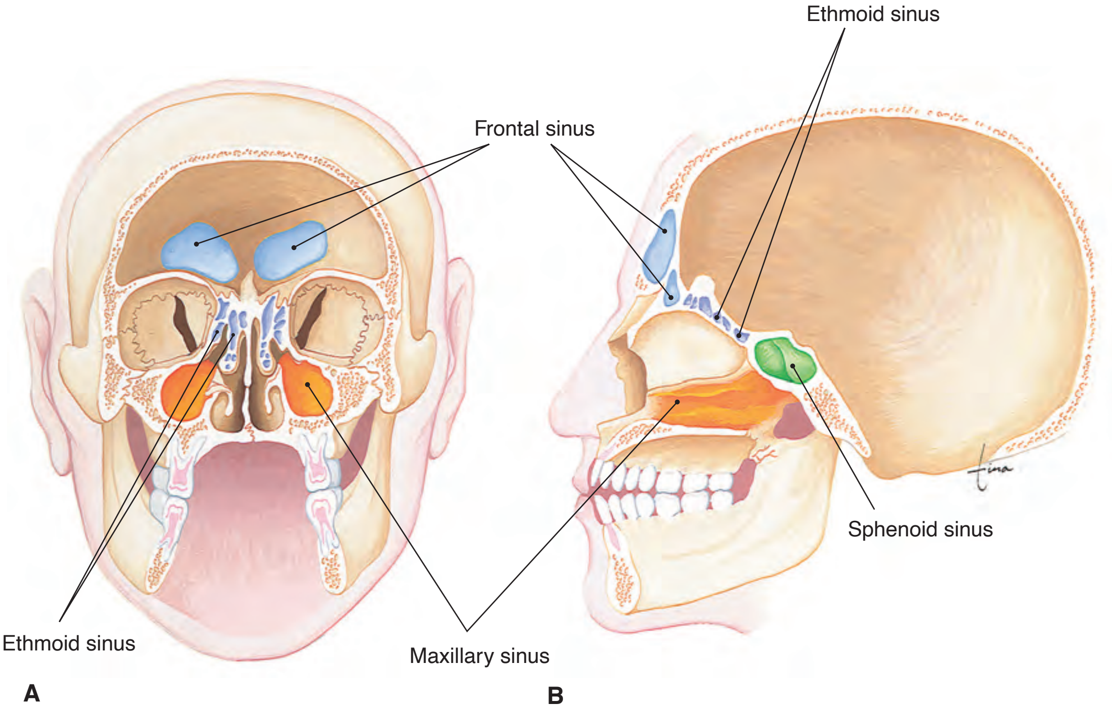


Figure 6–9 Paranasal sinuses. (**A**) Anterior view of the skull. (**B**) Left lateral view of skull.

QUESTION: Which of these sinuses often cause the pain of a sinus headache?

Because there are so many joints, the backbone as a whole is quite flexible (see also Box 6–3: Herniated Disc).

The normal spine in anatomic position has four natural curves, which are named after the vertebrae that form them. Refer to Fig. 6–10, and notice that the cervical curve is forward, the thoracic curve backward, the lumbar curve forward, and the sacral curve backward. These curves center the skull over the rest of the body, which enables a person to more easily walk upright (see Box 6–4: Abnormalities of the Curves of the Spine).

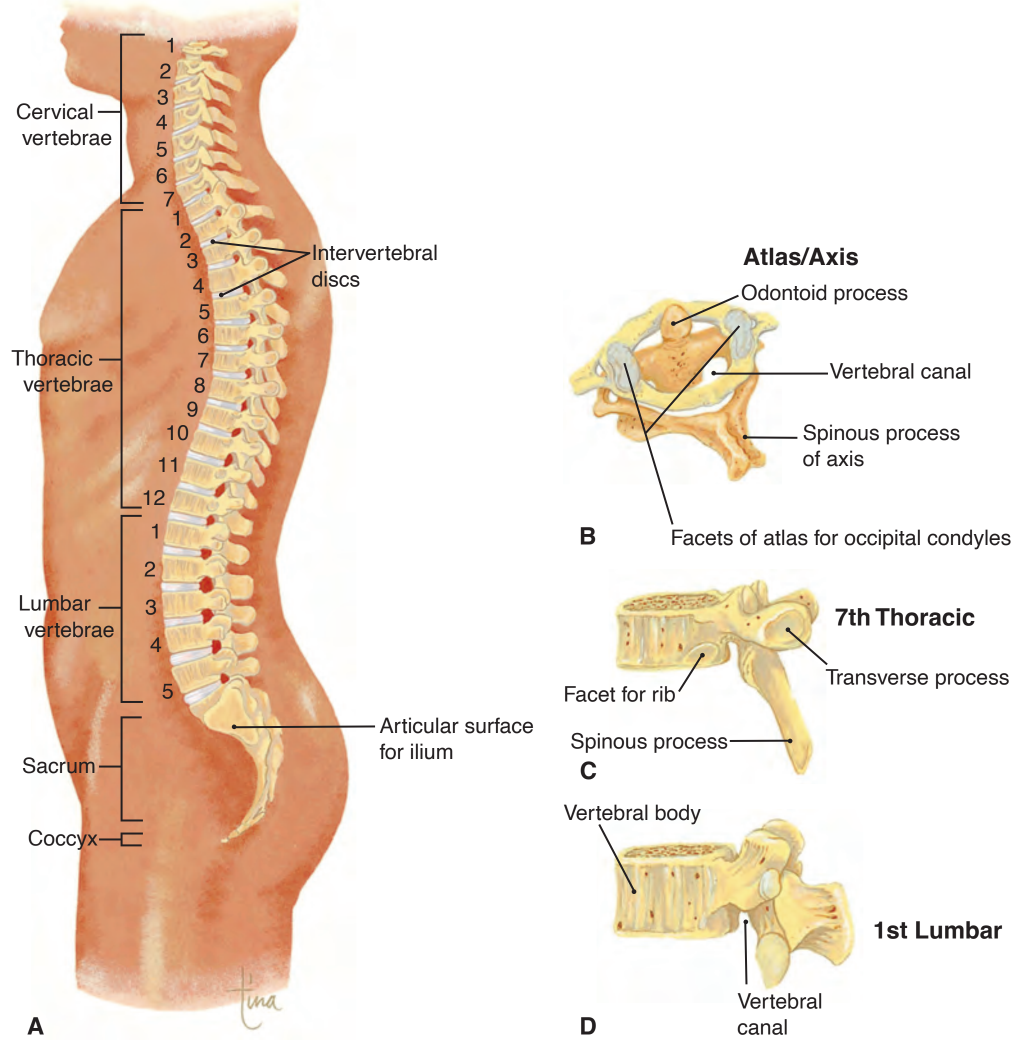


Figure 6–10 Vertebral column. (**A**) Lateral view of left side. (**B**) Atlas and axis, superior view. (**C**) 7th thoracic vertebra, left lateral view. (**D**) 1st lumbar vertebra, left lateral view.

QUESTION: Compare the size of the individual thoracic and lumbar vertebrae. What is the reason for this difference?

RIB CAGE

The **rib cage** consists of the 12 pairs of ribs and the sternum, or breastbone. The three parts of the sternum are the upper **manubrium**, the central **body**, and the lower **xiphoid process** (Fig. 6–11). Notice in Fig. 6–4 that the manubrium articulates with the clavicles.

All of the **ribs** articulate posteriorly with the thoracic vertebrae. The first seven pairs of ribs are called **true ribs**; they articulate directly with the manubrium and body of the sternum by means of costal cartilages. The next three pairs are called **false ribs**; their cartilages join the 7th rib cartilage. The last two pairs are called **floating ribs** because they do not articulate with the sternum at all (see Fig. 6–11).

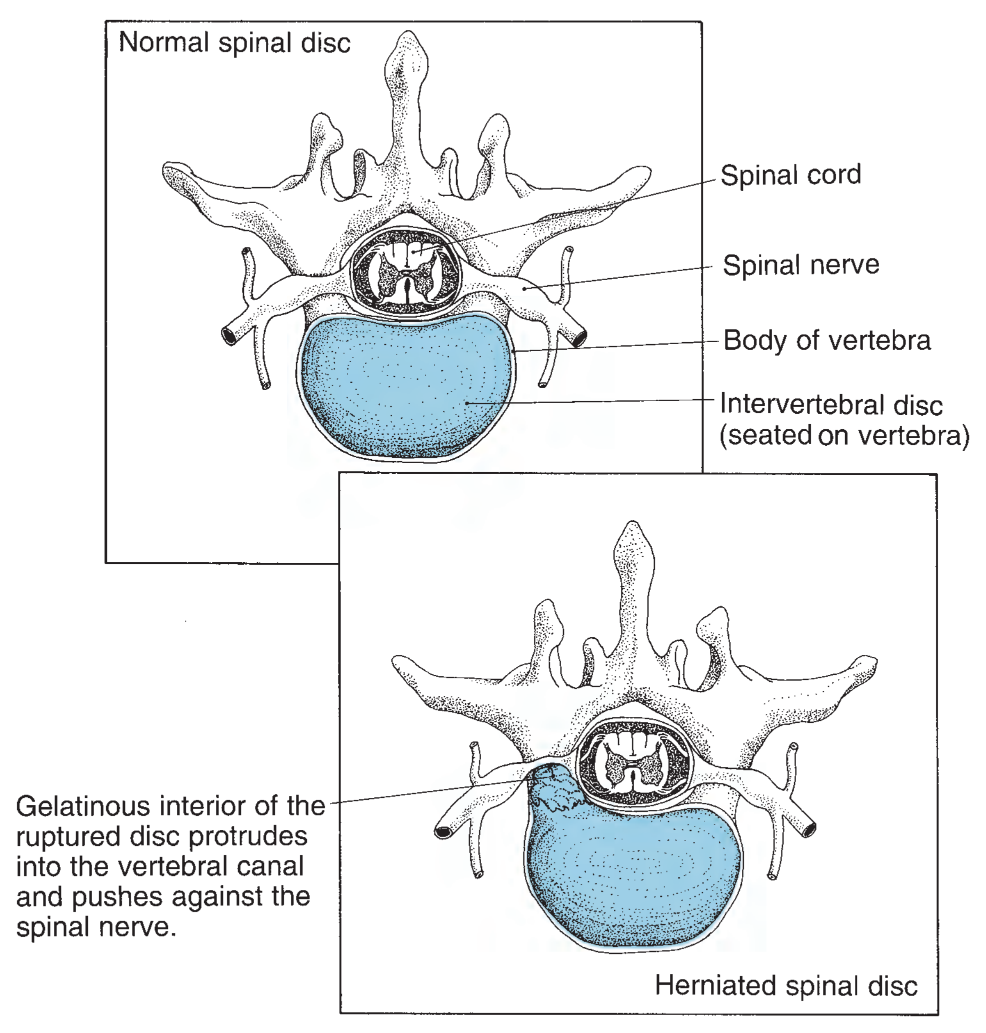
An obvious function of the rib cage is that it encloses and protects the heart and lungs. Keep in mind, though, that the rib cage also protects organs in the upper abdominal cavity, such as the liver and spleen. The other important function of the rib cage depends on its flexibility: The ribs are pulled upward and outward by the external intercostal muscles. This enlarges the chest cavity, which expands the lungs and contributes to inhalation.

Box 6–3 | HERNIATED DISC

The vertebrae are separated by discs of fibrous cartilage that act as cushions to absorb shock. An intervertebral disc has a tough outer covering and a soft center called the nucleus pulposus. Extreme pressure on a disc may rupture the outer layer and force the nucleus pulposus out. This may occur when a person lifts a heavy object improperly, that is, using the back rather than the legs and jerking upward, which puts sudden, intense pressure on the spine. Most often this affects discs in the lumbar region.

Although often called a "slipped disc," the affected disc is usually not moved out of position. The terms **herniated disc** or **ruptured disc** more accurately describe what happens. The nucleus pulposus is forced out, often posteriorly, where it puts pressure on a spinal nerve (Box Fig. 6–C). For this reason a herniated disc may be very painful or impair function in the muscles supplied by the nerve.

Healing of a herniated disc may occur naturally if the damage is not severe and the person rests and avoids activities that would further compress the disc. Surgery may be required, however, to remove the portion of the nucleus pulposus that is out of place and disrupting nerve functioning.


Normal spinal disc
Spinal cord
Spinal nerve
Body of vertebra
Intervertebral disc (seated on vertebra)
Gelatinous interior of the ruptured disc protrudes into the vertebral canal and pushes against the spinal nerve.
Herniated spinal disc

Box Figure 6–C Herniated disc. As a result of compression, a ruptured intervertebral disc puts pressure on a spinal nerve.

Box 6–4 | ABNORMALITIES OF THE CURVES OF THE SPINE

Scoliosis—an abnormal lateral curvature, which may be congenital, the result of having one leg longer than the other, or the result of chronic poor posture during childhood while the vertebrae are still growing. Usually the thoracic vertebrae are affected, which displaces the rib cage to one side. In severe cases, the abdominal organs may be compressed, and the expansion of the rib cage during inhalation may be impaired.

Kyphosis*—an exaggerated thoracic curve; sometimes referred to as hunchback.

Lordosis*—an exaggerated lumbar curve; sometimes referred to as swayback.

These abnormal curves are usually the result of degenerative bone diseases such as osteoporosis or tuberculosis of the spine. If osteoporosis, for example, causes the bodies of the thoracic vertebrae to collapse, the normal thoracic curve will be increased. Most often the vertebral body "settles" slowly (rather than collapses suddenly) and there is little, if any, damage to the spinal nerves. The damage to the vertebrae, however, cannot be easily corrected, so these conditions should be thought of in terms of prevention rather than cure.

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*Although descriptive of normal anatomy, the terms *kyphosis* and *lordosis*, respectively, are commonly used to describe the abnormal condition associated with each.

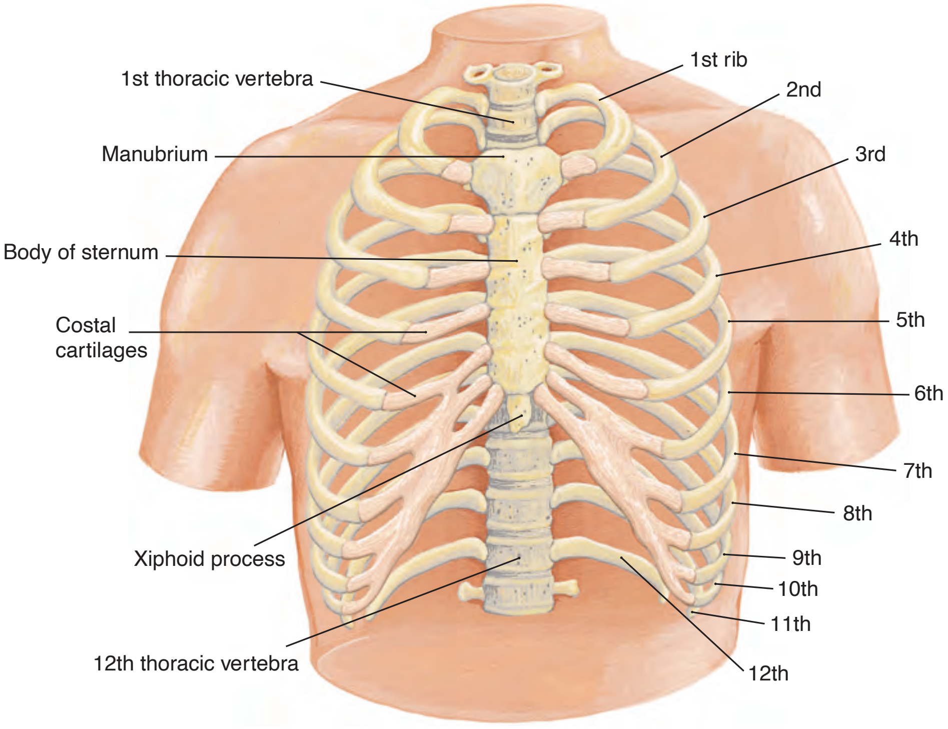


Figure 6–11 Rib cage. Anterior view.

QUESTION: With what bones do all of the ribs articulate?

THE SHOULDER AND ARM

The shoulder girdles attach the arms to the axial skeleton. Each consists of a scapula (shoulder blade) and clavicle (collarbone). The **scapula** is a large, flat bone with several projections (the spine of the scapula, the coracoid process) that anchor some of the muscles that move the upper arm and the forearm. A shallow depression called the glenoid fossa forms a **ball-and-socket joint** with the humerus, the bone of the upper arm (Fig. 6–12). If you look at the posterior view of the skeleton in Fig. 6–4, you will see that the scapulae do not articulate with the backbone, but seem to be resting on the rib cage. Each scapula is held in place on the rib cage by many muscles that are anchored to the backbone and to the humerus.

The medial end of each **clavicle** articulates with the manubrium of the sternum. At the base of your neck, you can feel the space between the two clavicles; this is the interclavicular notch, also called the suprasternal notch. The lateral end of each clavicle articulates with the scapula on its own side. In their position between the scapulae and the sternum, the clavicles act as braces for the scapulae and prevent the shoulders from coming too far forward. Although the shoulder joint is capable of a wide range of movement, the shoulder itself must be relatively stable if these movements are to be effective.

The **humerus** is the long bone of the upper arm. In Fig. 6–12, notice the deltoid tubercle (or tuberosity); the triangular deltoid muscle that caps the shoulder joint is anchored here. Proximally, the head of the humerus forms a ball-and-socket joint with the scapula. Distally, the humerus forms a **hinge joint** with the ulna of the forearm. This hinge joint, the elbow, permits movement in one plane, that is, back and forth with no lateral movement.

The forearm bones are the **ulna** on the little finger side and the **radius** on the thumb side. The semilunar notch of the ulna is part of the hinge joint of the elbow; it articulates with the trochlea of the humerus. The radius and ulna articulate proximally to form a **pivot joint**, which permits turning the hand palm up to palm down. You can demonstrate this yourself by holding your arm palm up in front of you, and noting that the radius and ulna are parallel to each other. Then turn your hand palm down, and notice that your upper arm does not move. The radius crosses over the ulna, which permits the hand to perform a great variety of movements without moving the entire arm.

The **carpals** are eight small bones in the wrist; **gliding joints** between them permit a sliding movement. The carpals also articulate with the distal ends of the ulna and radius, and with the proximal ends of the **metacarpals**, the five bones of the palm of the hand. All of the joints formed by the carpals and metacarpals make the hand very flexible at the wrist (try this yourself: flexion to extension should be almost 180 degrees), but the thumb is more movable than the fingers because of its carpometacarpal joint. This is a **saddle joint**, which enables the thumb to cross over the palm, and permits gripping.

The **phalanges** are the bones of the fingers. There are two phalanges in each thumb and three in each of the fingers. Between phalanges are **hinge joints**, which permit movement in one plane. Important parts of the shoulder and arm bones are described in Table 6–3.

THE HIP AND LEG

The pelvic girdle (or pelvic bone) consists of the two **hipbones** (coxae or innominate bones), which articulate with the axial skeleton at the sacrum. Each hipbone has three major parts: the ilium, ischium, and pubis, and these are shown in Fig. 6–13, which depicts both a male and a female pelvis. The **ilium** is the flared, upper portion that forms the sacroiliac joint. The **ischium** is the lower, posterior part that we sit on. The **pubis** is the lower, most anterior part. The two pubic bones articulate with one another at the **pubic symphysis**, with a disc of fibrous cartilage between them. Notice the pubic angle of both the male and female pelvises in Fig. 6–13. The wider female angle is an adaptation for childbirth, in that it helps make the pelvic outlet larger.

The **acetabulum** is the socket in the hipbone that forms a **ball-and-socket joint** with the femur. Compared with the glenoid fossa of the scapula, the acetabulum is a much deeper socket. This has great functional importance because the hip is a weight-bearing joint, whereas the shoulder is not. Because the acetabulum is deep, the hip joint is not easily dislocated, even by activities such as running and jumping (landing), which put great stress on the joint.

The **femur** is the long bone of the thigh. As mentioned, the femur forms a very movable ball-and-socket joint with the hipbone. At the proximal end of the femur are the greater and lesser trochanters, large projections that are anchors for muscles. At its distal end, the femur forms a **hinge joint**, the knee, with the tibia of the lower leg. Notice in Fig. 6–14 that each bone has condyles, which are the rounded projections that actually form the joint. The **patella**, or kneecap, is anterior to the knee joint, enclosed in the tendon of the quadriceps femoris, a large muscle group of the anterior thigh.

The **tibia** is the weight-bearing bone of the lower leg. You can feel the tibial tuberosity (a bump) and anterior crest (a ridge) on the front of your own leg. The medial malleolus, what we may call the “inner ankle bone,” is at

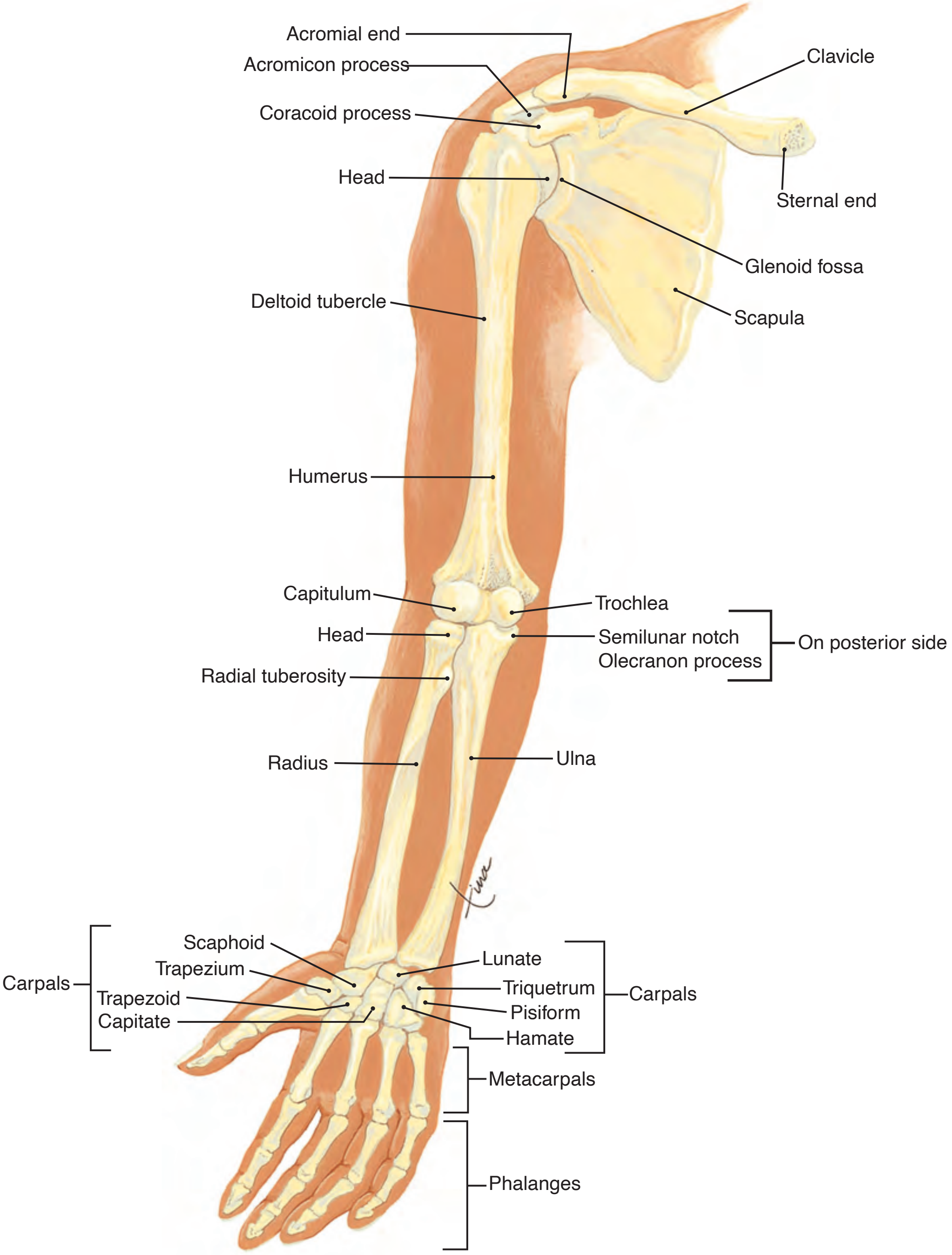


Figure 6–12 Bones of arm and shoulder girdle. Anterior view of right arm.

QUESTION: What types of joints are found in the arm? Begin at the shoulder and work downward.

Table 6–3 | BONES OF THE SHOULDER AND ARM—IMPORTANT PARTS

BONE	PART	DESCRIPTION
Scapula	Glenoid fossa	■ Depression that articulates with humerus
	Spine	■ Long, posterior process for muscle attachment
	Acromion process	■ Articulates with clavicle
Clavicle	Acromial end	■ Articulates with scapula
	Sternal end	■ Articulates with manubrium of sternum
Humerus	Head	■ Round process that articulates with scapula
	Deltoid tubercle	■ Round process for the deltoid muscle
	Olecranon fossa	■ Posterior, oval depression for the olecranon process of the ulna
	Capitulum	■ Round process superior to radius
	Trochlea	■ Concave surface that articulates with ulna
Radius	Head	■ Articulates with the ulna
Ulna	Olecranon process	■ Fits into olecranon fossa of humerus
	Semilunar notch	■ "Half-moon" depression that articulates with the trochlea of ulna
Carpals (8)	Scaphoid, Lunate, Triquetrum, Pisiform	■ Proximal row
	Trapezium, Trapezoid, Capitate, Hamate	■ Distal row

the distal end. Notice in Fig. 6–14 that the **fibula** is not part of the knee joint and does not bear much weight. The lateral malleolus of the fibula is the "outer ankle bone" you can find just above your foot. Though not a weight-bearing bone, the fibula is important in that leg muscles are attached and anchored to it, and it helps stabilize the ankle. Two bones on one is a much more stable arrangement than one bone on one, and you can see that the malleoli of the tibia and fibula overlap the sides of the talus. The tibia and fibula do not form a pivot joint as do the radius and ulna in the forearm; this also contributes to the stability of the lower leg and foot and the support of the entire body.

The **tarsals** are the seven bones in the ankle. As you would expect, they are larger and stronger than the carpals of the wrist, and their gliding joints do not provide nearly as much movement. The largest is the **calcaneus**, or heel bone; the **talus** transmits weight between the calcaneus and the tibia. **Metatarsals** are the five long bones of each foot, and **phalanges** are the bones of the toes. There are two phalanges in the big toe and three in each of the other toes. The phalanges of the toes form hinge joints with each other. Because there is no saddle joint in the foot, the big toe is not as movable as the thumb. The foot has two major arches, longitudinal and transverse, which are supported by ligaments. These are adaptations for walking completely upright, in that arches provide for spring or bounce in our steps. Important parts of hip and leg bones are described in Table 6–4.

JOINTS—ARTICULATIONS

A joint is where two bones meet, or articulate.

THE CLASSIFICATION OF JOINTS

The classification of joints is based on the amount of movement possible. A synarthrosis is an immovable joint, such as a suture between two cranial bones. An amphiarthrosis is a slightly movable joint, such as the symphysis joint between adjacent vertebrae. A diarthrosis is a freely movable joint. This is the largest category of joints and includes the ball-and-socket joint, the pivot, hinge, and others. Examples of each type of joint are described in Table 6–5, and many of these are illustrated in Fig. 6–15.

SYNOVIAL JOINTS

All diarthroses, or freely movable joints, are synovial joints because they share similarities of structure. A typical synovial

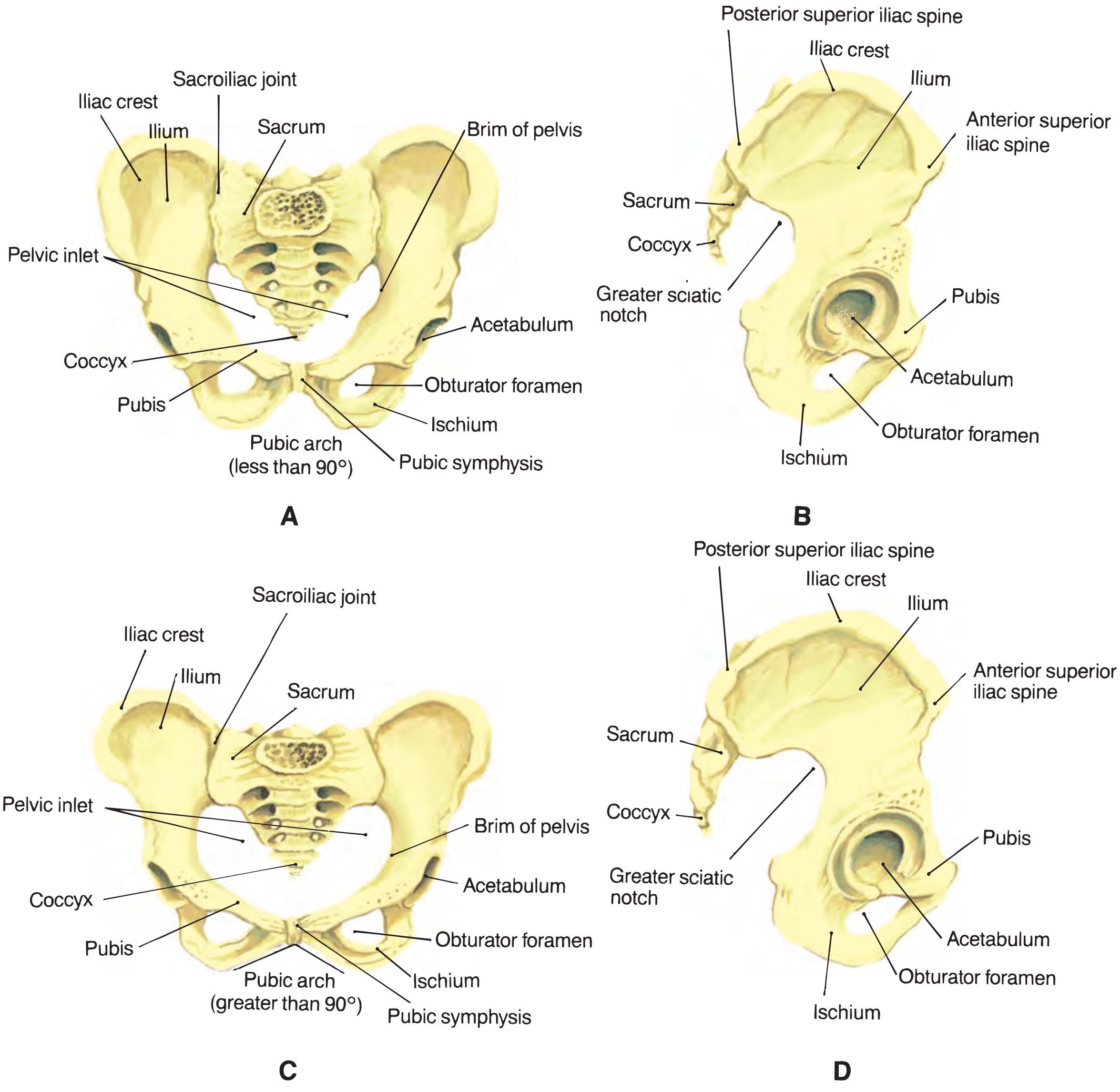


Figure 6–13 Hipbones and sacrum. (**A**) Male pelvis, anterior view. (**B**) Male pelvis, lateral view of right side. (**C**) Female pelvis, anterior view. (**D**) Female pelvis, lateral view of right side.

QUESTION: Compare the male and female pelvic inlets. What is the reason for this difference?

joint is shown in Fig. 6–16. On the joint surface of each bone is the **articular cartilage**, which provides a smooth surface. The **joint capsule**, made of fibrous connective tissue, encloses the joint in a strong sheath, like a sleeve. This capsule contributes to the stability of a joint. At the hip, for example, the joint capsule extends from the neck of the femur to the rim of the acetabulum and fits snugly, like a tight sleeve. The joint capsule at the shoulder has a more loose fit, which permits the shoulder joint greater range of motion. Lining the joint capsule is the synovial membrane, which secretes **synovial fluid** into the joint cavity. Synovial fluid is thick and slippery and prevents friction as the bones move.

Many synovial joints also have **bursae** (or bursas), which are small sacs of synovial fluid between the joint and the tendons that cross over the joint. Bursae permit the tendons to slide easily as the bones are moved. If

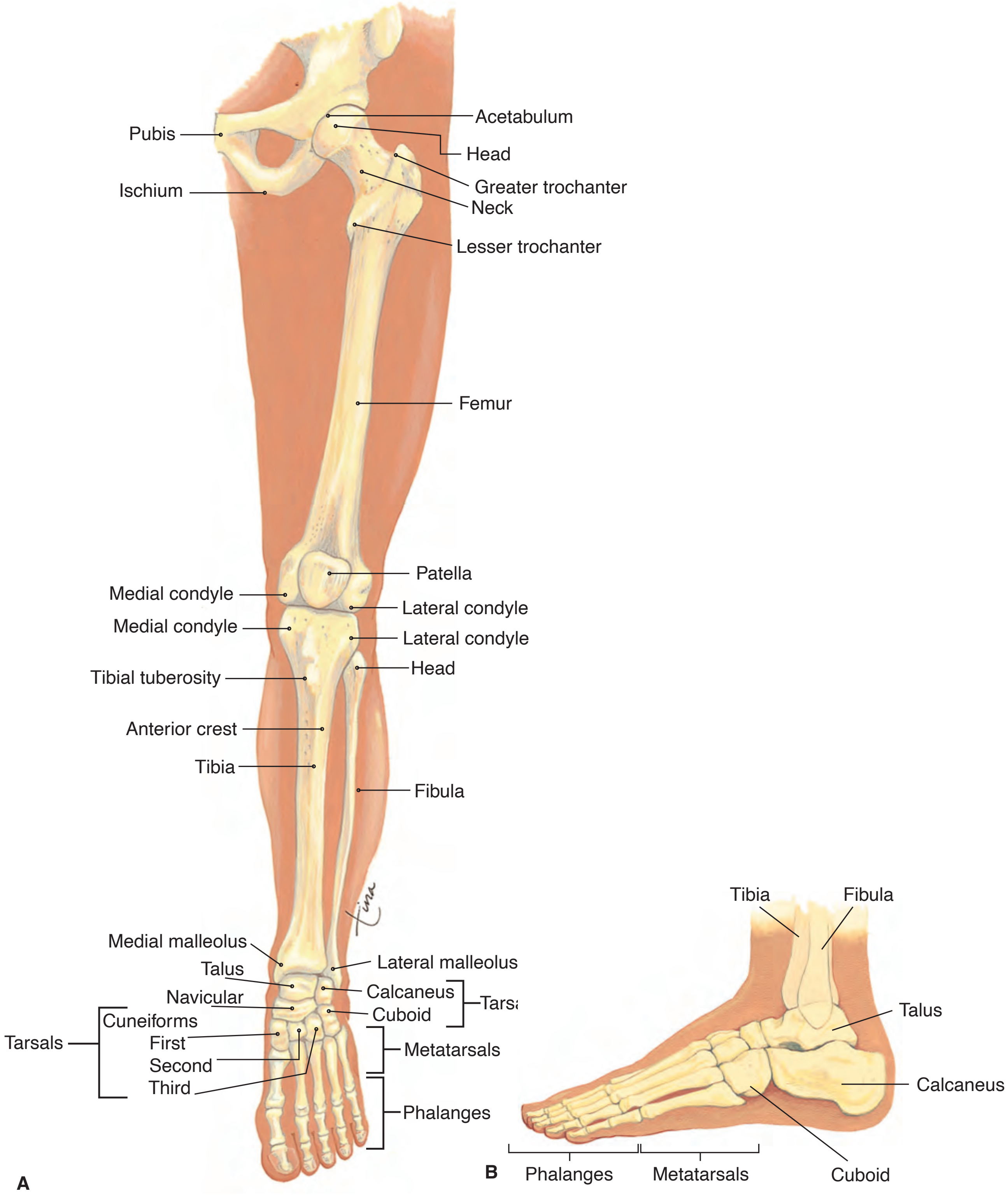


Figure 6–14 (**A**) Bones of the leg and portion of hipbone, anterior view of left leg. (**B**) Lateral view of left foot.

QUESTION: What types of joints found in the arm do not have counterparts in the leg?

Table 6–4 | BONES OF THE HIP AND LEG—IMPORTANT PARTS

BONE	PART	DESCRIPTION
Pelvic (2 hip bones)	Ilium	■ Flared, upper portion
	Iliac crest	■ Upper edge of ilium
	Posterior superior iliac spine	■ Posterior continuation of iliac crest
	Ischium	■ Lower, posterior portion
	Pubis	■ Anterior, medial portion
	Pubic symphysis	■ Joint between the 2 pubic bones
	Acetabulum	■ Deep depression that articulates with femur
Femur	Head	■ Round process that articulates with hip bone
	Neck	■ Constricted portion distal to head
	Greater trochanter	■ Large lateral process for muscle attachment
	Lesser trochanter	■ Medial process for muscle attachment
	Condyles	■ Rounded processes that articulate with tibia
Tibia	Condyles	■ Articulate with the femur
	Tibial tuberosity	■ Round process for the patellar ligament
	Anterior crest	■ Vertical ridge
	Medial malleolus	■ Distal process; medial “ankle bone”
Fibula	Head	■ Articulates with tibia
	Lateral malleolus	■ Distal process; lateral “ankle bone”
Tarsals (7)	Calcaneus	■ Heel bone
	Talus	■ Articulates with calcaneus and tibia
	Cuboid, navicular	—
	Cuneiform: 1st, 2nd, 3rd	—

Table 6–5 | TYPES OF JOINTS

CATEGORY	TYPE AND DESCRIPTION	EXAMPLES
Synarthrosis (immovable)	Suture—fibrous connective tissue between bone surfaces	■ Between cranial bones ■ Between facial bones
Amphiarthrosis (slightly movable)	Symphysis—disc of fibrous cartilage between bones	■ Between vertebrae ■ Between pubic bones
Diarthrosis (freely movable)	Ball and socket—movement in all planes	■ Scapula and humerus ■ Pelvic bone and femur
	Hinge—movement in one plane	■ Humerus and ulna ■ Femur and tibia ■ Between phalanges
	Condyloid—movement in one plane with some lateral movement	■ Temporal bone and mandible
	Pivot—rotation	■ Atlas and axis ■ Radius and ulna
	Gliding—side-to-side movement	■ Between carpals ■ Sacrum and ilium
	Saddle—movement in several planes	■ Carpometacarpal of thumb

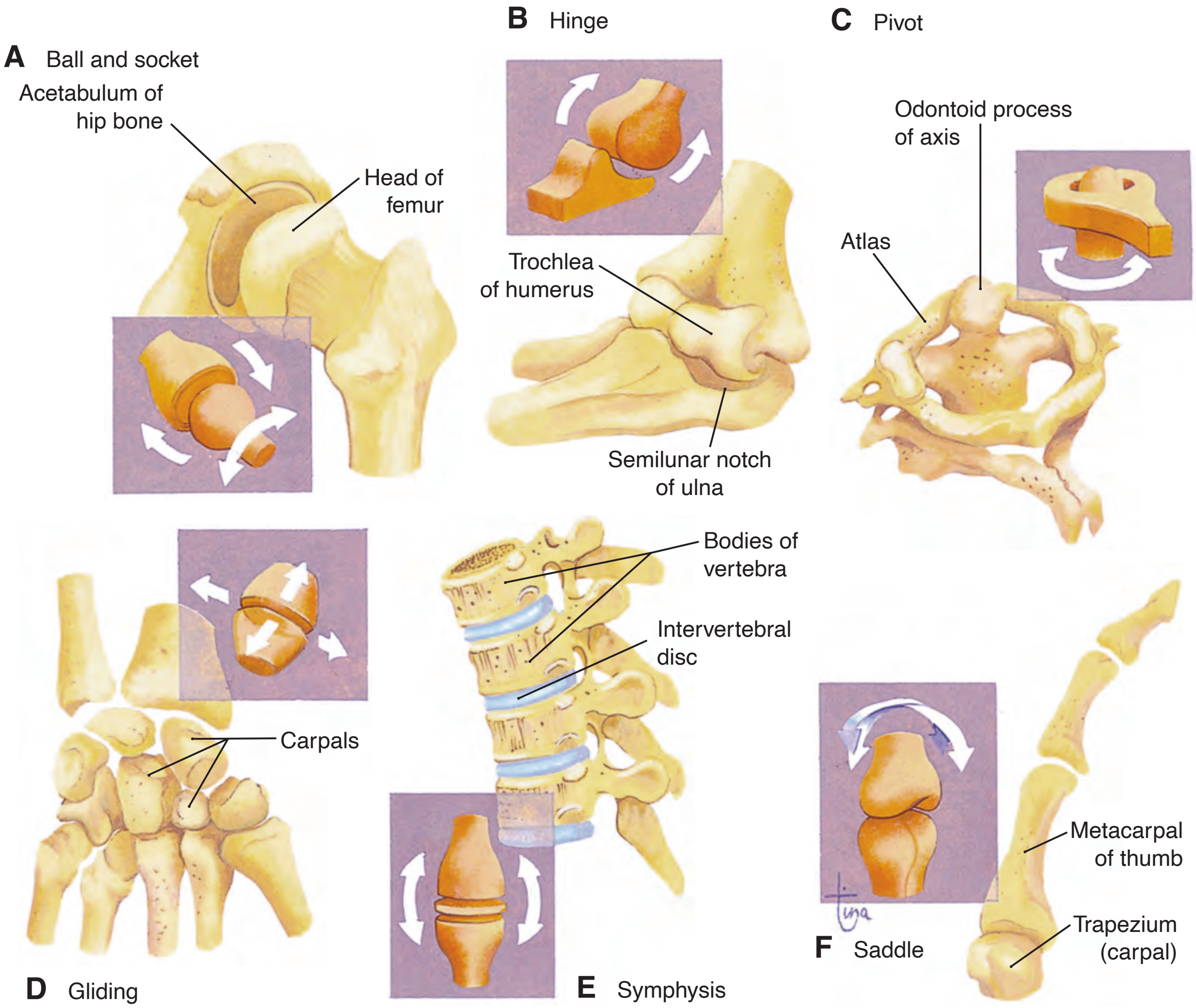


Figure 6–15 Types of joints. For each type, a specific joint is depicted, and a simple diagram shows the position of the joint surfaces. (**A**) Ball and socket. (**B**) Hinge. (**C**) Pivot. (**D**) Gliding. (**E**) Symphysis. (**F**) Saddle.

QUESTION: Which of these types of joints is most movable? Which is least movable?

a joint is used excessively, the bursae may become inflamed and painful; this condition is called **bursitis**. Some other disorders of joints are described in Box 6–5: Arthritis.

AGING AND THE SKELETAL SYSTEM

With age, bone tissue tends to lose more calcium than is replaced. Bone matrix becomes thinner, the bones themselves become more brittle, and fractures are more likely to occur with mild trauma.

Erosion of the articular cartilages of joints is also a common consequence of aging. Joints affected include weight-bearing joints such as the knees and active, small joints such as those of the fingers.

Although the normal wear and tear of joints cannot be prevented, elderly people can preserve their bone matrix with exercise (dancing counts) and diets high in calcium and vitamin D.

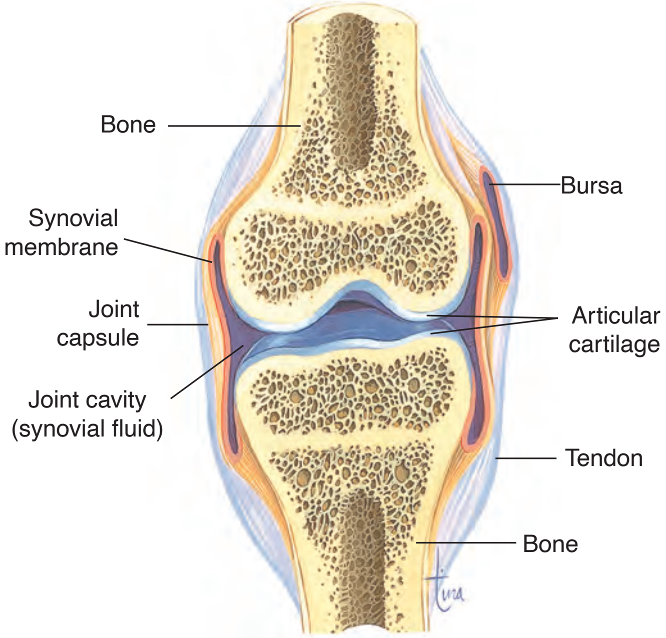


Figure 6–16 Structure of a synovial joint. See text for description.

QUESTION: How can you tell that this is a joint between two long bones? Give an example of two such bones.

Box 6–5 | ARTHRITIS

The term **arthritis** means "inflammation of a joint." Of the many types of arthritis, we will consider two: osteoarthritis and rheumatoid arthritis.

Osteoarthritis is a natural consequence of getting older. In joints that have borne weight for many years, the articular cartilage is gradually worn away. The once smooth joint surface becomes rough, and the affected joint is stiff and painful. As you might guess, the large, weight-bearing joints are most often subjected to this form of arthritis. If we live long enough, most of us can expect some osteoarthritis in knees, hips, or ankles.

Rheumatoid arthritis (RA) can be a truly crippling disease that may begin in early middle age or, less commonly, during adolescence. It is an **autoimmune disease**, which means that the immune system mistakenly directs its destructive capability against part of the body. Exactly what triggers this abnormal response by the immune system is not known with certainty, but certain bacterial and viral infections have been suggested as possibilities.

Rheumatoid arthritis often begins in joints of the extremities, such as those of the fingers. The autoimmune activity seems to affect the synovial membrane, and joints become painful and stiff. Sometimes the disease progresses to total destruction of the synovial membrane and calcification of the joint. Such a joint is then fused and has no mobility at all. Autoimmune damage may also occur in the heart and blood vessels, and those with RA are more prone to heart attacks and strokes (RA is a systemic, not a localized, disease).

Treatment of rheumatoid arthritis is directed at reducing inflammation as much as possible, because it is the inflammatory process that causes the damage. Therapies being investigated involve selectively blocking specific aspects of the immune response, such as antibody production. At present there is no cure for autoimmune diseases.

SUMMARY

Your knowledge of the bones and joints will be useful in the next chapter as you learn the actions of the muscles that move the skeleton. It is important to remember, however, that bones have other functions as well. As a storage site for excess calcium, bones contribute to the maintenance of a normal blood calcium level. The red bone marrow found in flat and irregular bones produces the blood cells: red blood cells, white blood cells, and platelets. Some bones protect vital organs such as the brain, heart, and lungs. As you can see, bones themselves may also be considered vital organs.

STUDY OUTLINE

The skeleton is made of bone and cartilage and has these functions:

1. Is a framework for support, connected by ligaments, moved by muscles.
2. Protects internal organs from mechanical injury.
3. Contains and protects red bone marrow.
4. Stores excess calcium; important to regulate blood calcium level.

Bone Tissue (see Fig. 6–1)

1. Osteocytes (cells) are found in the matrix of calcium phosphate, calcium carbonate, and collagen.
2. Compact bone—haversian systems are present.
3. Spongy bone—no haversian systems; red bone marrow present.
4. Articular cartilage—smooth, on joint surfaces.
5. Periosteum—fibrous connective tissue membrane; anchors tendons and ligaments; has blood vessels that enter the bone.

Classification of Bones

1. Long—arms, legs; shaft is the diaphysis (compact bone) with a marrow cavity containing yellow bone marrow (fat); ends are epiphyses (spongy bone) (see Fig. 6–1).
2. Short—wrists, ankles (spongy bone covered with compact bone).
3. Flat—ribs, pelvic bone, cranial bones (spongy bone covered with compact bone).
4. Irregular—vertebrae, facial bones (spongy bone covered with compact bone).

Embryonic Growth of Bone

1. The embryonic skeleton is first made of other tissues that are gradually replaced by bone. Ossification begins in the third month of gestation; osteoblasts differentiate from fibroblasts and produce bone matrix.
2. Cranial and facial bones are first made of fibrous connective tissue; osteoblasts produce bone matrix in a center of ossification in each bone; bone growth radiates outward; fontanels remain at birth to permit compression of the infant skull during birth; fontanels are calcified by age 2 (see Fig. 6–2).
3. All other bones are first made of cartilage. In a long bone the first center of ossification is in the diaphysis; other centers develop in the epiphyses. After birth a long bone grows at the epiphyseal discs: Cartilage is produced on the epiphysis side, and bone replaces cartilage on the diaphysis side. Osteoclasts form the marrow cavity by reabsorbing bone matrix in the center of the diaphysis (see Fig. 6–3).

Factors That Affect Bone Growth and Maintenance

1. Heredity—many pairs of genes contribute to genetic potential for height.
2. Nutrition—calcium, phosphorus, and protein become part of the bone matrix; vitamin D is needed for absorption of calcium in the small intestine; vitamins C and A are needed for bone matrix production (calcification).
3. Hormones—produced by endocrine glands; concerned with cell division, protein synthesis, calcium metabolism, and energy production (see Table 6–1).

4. Other tissues—leptin from adipose tissue stimulates bone growth; serotonin from the small intestine inhibits bone growth.
5. Exercise or stress—weight-bearing bones must bear weight or they will lose calcium and become brittle.

The Skeleton—206 bones (see Fig. 6–4); bones are connected by ligaments

1. Axial—skull, vertebrae, rib cage.
    a. Skull—see Figs. 6–5 through 6–8 and Table 6–2.
        - Eight cranial bones form the braincase, which also protects the eyes and ears; 14 facial bones make up the face; the immovable joints between these bones are called sutures.
        - Paranasal sinuses are air cavities in the maxillae, frontal, sphenoid, and ethmoid bones; they lighten the skull and provide resonance for voice (see Fig. 6–9).
        - Three auditory bones in each middle ear cavity transmit vibrations for hearing.

    b. Vertebral column—see Fig. 6–10.
        - Individual bones are called vertebrae: 7 cervical, 12 thoracic, 5 lumbar, 5 sacral (fused into one sacrum), 4 to 5 coccygeal (fused into one coccyx). Supports trunk and head, encloses and protects the spinal cord in the vertebral canal. Discs of fibrous cartilage absorb shock between the bodies of adjacent vertebrae, also permit slight movement. Four natural curves center head over body for walking upright (see Table 6–5 for joints).

    c. Rib cage—see Fig. 6–11.
        - Sternum and 12 pairs of ribs; protects thoracic and upper abdominal organs from mechanical injury and is expanded to contribute to inhalation. Sternum consists of manubrium, body, and xiphoid process. All ribs articulate with thoracic vertebrae; true ribs (first seven pairs) articulate directly with sternum by means of costal cartilages; false ribs (next three pairs) articulate with 7th costal cartilage; floating ribs (last two pairs) do not articulate with the sternum.

2. Appendicular—bones of the arms and legs and the shoulder and pelvic girdles.
    a. Shoulder and arm—see Fig. 6–12 and Table 6–3.
        - Scapula—shoulder muscles are attached; glenoid fossa articulates with humerus.
        - Clavicle—braces the scapula.
        - Humerus—upper arm; articulates with the scapula and the ulna (elbow).
        - Radius and ulna—forearm—articulate with one another and with carpals.
        - Carpals (8)—wrist; metacarpals (5)—hand; phalanges (14)—fingers (for joints, see Table 6–5).

    b. Hip and leg—see Figs. 6–13 and 6–14 and Table 6–4.
        - Pelvic bone—two hipbones; ilium, ischium, pubis; acetabulum articulates with femur.
        - Femur—thigh; articulates with pelvic bone and tibia (knee).
        - Patella—kneecap; in tendon of quadriceps femoris muscle.
        - Tibia and fibula—lower leg; tibia bears weight; fibula does not bear weight, but does anchor muscles and stabilizes ankle.
        - Tarsals (7)—ankle; calcaneus is heel bone.
        - Metatarsals (5)—foot; phalanges (14)—toes (see Table 6–5 for joints).

Joints—Articulations

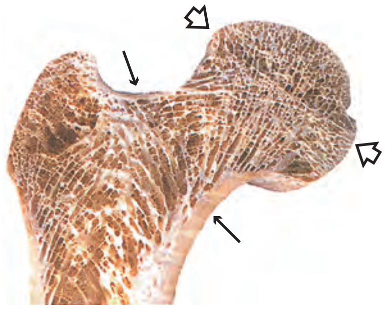
1. Classification based on amount of movement:
    a. Synarthrosis—immovable.
    b. Amphiarthrosis—slightly movable.
    c. Diarthrosis—freely movable (see Table 6–5 for examples; see also Fig. 6–15).
2. Synovial joints—all diarthroses have similar structure (see Fig. 6–16):
    a. Articular cartilage—smooth on joint surfaces.
    b. Joint capsule—strong fibrous connective tissue sheath that encloses the joint.
    c. Synovial membrane—lines the joint capsule; secretes synovial fluid that prevents friction.
    d. Bursae—sacs of synovial fluid that permit tendons to slide easily across joints.

REVIEW QUESTIONS

1. Explain the differences between compact bone and spongy bone, and state where each type is found. (p. 122)
2. State the locations of red bone marrow, and name the blood cells it produces. (p. 122)
3. Name the tissue of which the embryonic skull is first made. Explain how ossification of cranial bones occurs. (p. 124)
4. State what fontanels are, and explain their function. (pp. 124–125)
5. Name the tissue of which the embryonic femur is first made. Explain how ossification of this bone occurs. Describe what happens in epiphyseal discs to produce growth of long bones. (p. 125)
6. Explain what is meant by "genetic potential" for height, and name the nutrients a child must have in order to attain genetic potential. (p. 125)
7. Explain the functions of calcitonin and parathyroid hormone with respect to bone matrix and to blood calcium level. (p. 128)
8. Explain how estrogen or testosterone affects bone growth and when. (p. 125)
9. State one way each of the following hormones helps promote bone growth: insulin, thyroxine, growth hormone. (p. 128)
10. Name the bones that make up the braincase. (pp. 129–130)
11. Name the bones that contain paranasal sinuses and explain the functions of these sinuses. (p. 131)
12. Name the bones that make up the rib cage, and describe two functions of the rib cage. (p. 137)
13. Describe the functions of the vertebral column. State the number of each type of vertebra. (p. 131)
14. Explain how the shoulder and hip joints are similar and how they differ. (pp. 140–142)
15. Give a specific example (name two bones) for each of the following types of joints: (p. 145)
    - a. Hinge
    - b. Symphysis
    - c. Pivot
    - d. Saddle
    - e. Suture
    - f. Ball and socket
16. Name the part of a synovial joint with each of the following functions: (p. 143)
    - a. Fluid within the joint cavity that prevents friction
    - b. Encloses the joint in a strong sheath
    - c. Provides a smooth surface on bone surfaces
    - d. Lines the joint capsule and secretes synovial fluid
17. Refer to the diagram of the full skeleton (Fig. 6–4), and point to each bone on yourself. (p. 130)

FOR FURTHER THOUGHT

1. Following a severe spinal cord injury in the lumbar region, the voluntary muscles of the legs and hips will be paralyzed. Describe the effects of paralysis on the skeleton.
2. Without looking at any of the illustrations, try to name all the bones that form the orbits, the sockets for the eyes. Check your list with Figs. 6–5 and 6–6.
3. In an effort to prevent sudden infant death syndrome (SIDS), parents were advised to put their infants to sleep lying on their backs, not their stomachs. Since then (1994), the number of SIDS deaths has decreased markedly. What do you think has happened to the skulls of many of those infants? Explain.
4. A 5-month-old infant is brought to a clinic after having diarrhea for 2 days. The nurse checks the baby's anterior fontanel and notices that it appears sunken. What has caused this?
5. Look at the lateral view of the adult skull in Fig. 6–5 and notice the size of the face part in proportion to the braincase part. Compare the infant skull in Fig. 6–2, and notice how small the infant face is relative to the size of the braincase. There is a very good reason for this. What do you think it is?
6. Look at the photograph here, Question Fig. 6–A. Name the bone and the type of section in which it is cut. What are the large arrows indicating? What are the smaller arrows indicating? Look carefully at this site, describe it, and explain possible consequences.



QUESTION FIGURE 6–A (Photograph by Dan Kaufman.)